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GARY MICHAEL JOHN MASSE

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VINYLPHOSPHONIUM AND SULFONIUM SALTS
AS SYNTHETIC REAGENTS

by

Gary Michael John Masse

A Dissertation

Submitted to the Faculty of Graduate Studies through the
Department of Chemistry in Partial Fulfillment
of the Requirements for the Degree of
Doctor of Philosophy at the
University of Windsor

Windsor, Ontario

1977



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1977

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To Carol

ABSTRACT

α -Mercaptocarbonyl compounds react with vinylphosphonium salts to yield a new, general synthesis of alkylated 2,5-dihydrothiophenes. Peracid oxidation of the 2,5-dihydrothiophenes occurs at sulfur to produce 2,5-dihydrothiophene 1,1-dioxides. We have demonstrated the synthetic utility of these sulfones in the preparation of conjugated dienes. Evidence is presented which shows that cis-2,5-dihydrothiophenes are formed in preference to the trans isomers. This result is explained on a steric basis. The implications of this result for the stereoselective synthesis of conjugated dienes are discussed.

Spectral data suggest that the reaction of α -mercaptocarbonyl compounds and vinylsulfonium salts affords alkylated 3,4-epoxytetrahydrothiophenes, but in poor yield. The major reaction involves the nucleophilic dealkylation of the vinyl dialkylsulfonium salts by the thiolate anion to yield α -alkylthiocarbonyl compounds and alkyl vinyl sulfides. The ramifications of this reaction are discussed. Also, a number of new vinylsulfonium salts is prepared.

A useful synthesis of β -bromosulfonium salts is reported. This reaction involves the electrophilic addition of bromodimethylsulfonium bromide to olefins and appears to follow Markownikov addition. Dehydrohalogenation of these salts to vinylsulfonium salts is accomplished with silver oxide. The use of β -bromosulfonium salts as synthons for vinylsulfonium salts is examined.

ACKNOWLEDGEMENTS

This dissertation is an oblation to my research director, Dr. John M. McIntosh, whose patience and counsel contributed more to the consummation of my goals as a graduate student than I can effectively express. My colleagues, the "organic boys", deserve the gratitude I now humbly express for the many helpful discussions and heated debates we encountered over the years. In particular, I would like to thank Hamdy, my friend and labmate; it is truly incredible the consistency with which we disagree.

Irrefutably, we are all human and because of this we tend to ignore or take for granted the people so necessary and dear to us. I tenderly would like to requite my parents and, especially, my typist and dear wife, Carol, whom I love.

Finally, the financial assistance of the National Research Council of Canada in the form of a scholarship to myself and operating grants to my director is gratefully acknowledged.

"Synthetic objectives are seldom, if ever, taken by chance, nor will the most painstaking or inspired, purely observational activities suffice. Synthesis must be carried out by plan, and the synthetic frontier can be defined only in terms of the degree to which realistic planning is possible, utilizing all of the intellectual and physical tools available."

R. B. Woodward,

"Perspectives in Organic Chemistry"

New York, N. Y., Interscience,
1956, p155.

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CHAPTER I

THE PREPARATION AND PROPERTIES OF SOME ALKYLATED

2,5-DIHYDROTHIOPHENES

INTRODUCTION

The construction of immense, natural molecules by rational synthetic pathways continues to impress the practising organic chemist. The esthetes, the most notable of which is R.B. Woodward, continue to attempt and conquer such molecular architecture. Woodward's uncanny ability has been demonstrated many times in, for example, the syntheses of cholesterol¹, strychnine², chlorophyll³, and vitamin B-12⁴. The only nemesis to these scientific artists is the limited selection of reagents available for the stereo- and regiospecific transformations which create both the proper framework and stereochemistry. Designing a simple procedure to carry out an otherwise multi-step reaction sequence can make the synthesis of complex molecules facile. To do this in a stereochemically pure manner makes complex syntheses practical.

The concept of the "synthon"⁵ (functional group equivalent) which was introduced by Corey⁶ forms a basis for computer-designed syntheses. It has been a noteworthy advance in the fight to establish methodology directed towards development of the synthetic plan. Again, however, this approach is limited by the available synthetic reactions. Thus, in order to rise to new heights in synthetic chemistry, new methods

must be discovered. The area of "new synthetic methods" has become very popular in recent years. Some of the most notable advances in this area stem from the novel and ingenious approaches of B. M. Trost which are exemplified by the use of cyclopropylsulfonium ylide 1 (Figure 1)⁷.

The wide applicability of the Diels-Alder reaction to the synthesis of complex molecules is well known⁸. Common dienophiles can be obtained in a variety of ways. Difficulty often is encountered in the preparation of the required diene in a regio- and stereochemically pure manner. Of course, stereoisomerically pure dienes and dienophiles are required if the stereochemical integrity of the Diels-Alder reaction is to be maximally utilized.

Classically⁹, conjugated dienes can be formed in a number of diverse ways. One general method employed is the acid-catalyzed dehydration of alcohols. The diene, 2,3-dimethyl-1,3-butadiene, may be prepared from pinacol by a variety of dehydrating agents such as hydrobromic acid¹⁰, aluminum oxide¹¹, and calcium phosphate¹² in yields as high as 86%. In a less direct method, trans-1-phenyl-1,3-butadiene 2 can be obtained in 72 - 75% by the acid hydrolysis of the adduct formed between cinnamaldehyde and methylmagnesium bromide¹³ (Figure 2). When proton acids catalyze

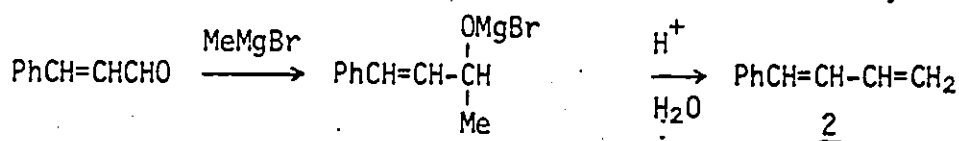


Figure 2. Synthesis of 1-Phenyl-1,3-Butadiene



Figure 1. Cyclopropylsulfonium ylide as a Synthetic Reagent.

alcohol dehydration, the mechanism is $E1^{9c}$. The principal process involves conversion of ROH to ROH_2^+ and cleavage of the latter to R^+ and H_2O .

Rarely, in the case of a carbenium ion mechanism does one have much control of the stereochemistry or regioselectivity.

The base-catalyzed dehydrohalogenation of allylic halides leads to conjugated dienes. For example, reaction of 3-chlorocyclohexene with N,N -dimethylaniline affords an 80% yield of cyclohexadiene¹⁶.

The Wittig reaction^{9b} has also been used in the preparation of 1,3-dienes. For example, triphenylcinnamylphosphonium chloride reacts with benzaldehyde and lithium ethoxide to give 1,4-diphenyl-1,3-butadiene 3 in 60 - 67% yield¹⁴ (Figure 3). When phosphonoesters are used, ethyl

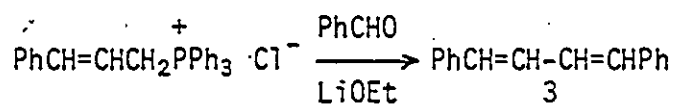


Figure 3. Use of Phosphonium Salts in Diene Preparation

5-arylpent-2,4-dienoates 4 can be prepared in 54 - 98% yield¹⁵ (Figure 4).

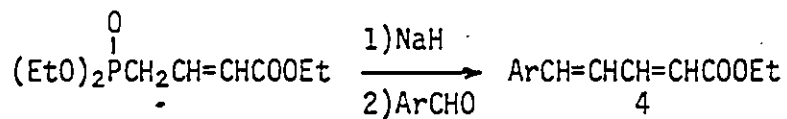


Figure 4. Phosphonoesters as Routes to Dienes

While the Wittig reaction does offer a regiospecific synthesis of conjugated dienes, the effect of reaction variables on the stereochemistry

of the reaction are not yet totally predictable²¹. For instance, the effect of solvent polarity and dissolved lithium salts on the stereochemistry of the Wittig reaction are not yet totally understood²¹. Furthermore, one of the chief drawbacks to the use of this reaction is the low yields encountered in the synthesis of tri- and tetrasubstituted double bonds^{8,9b,22}.

Nerdel²³ has demonstrated that olefin homologation with bromoform can lead to conjugated dienes but in low yields (Figure 5).

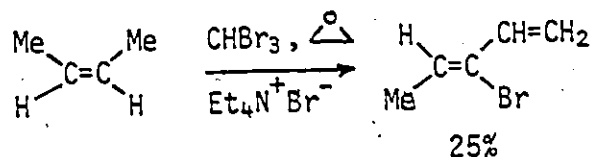


Figure 5. Nerdel's Diene Synthesis

Cohen²⁴ has reported that the copper-induced coupling of vinyl halides leads to dienes in a stereochemically stable manner. Coupling of iodofumarate led to a 96% isolated yield of trans,trans-1,2,3,4-tetracarboxy-1,3-butadiene (Figure 6).

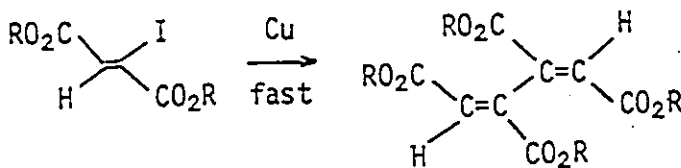


Figure 6. Copper-Induced Coupling of Vinyl Halides

Although the Ullman coupling reaction of vinyl halides does possess

synthetic potential, its use is limited to the isolation of symmetrical dienes. This problem can be circumvented to a certain extent by the use of palladium organometallics. Heck²⁵ has described a procedure whereby vinyl halides may be linked to other olefins by the use of bis-(triphenylphosphine)-palladium diacetate as outlined in Figure 7.

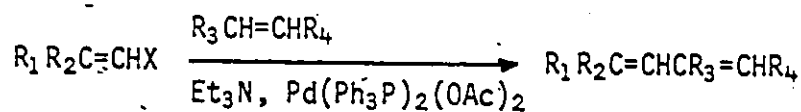


Figure 7. Palladium-catalyzed Linking of Olefins

Trost has reported that π -allylpalladium complexes react with olefins in the presence of metallated sulfoxides to yield dienes²⁶. This procedure is delineated in Figure 8. There is a high degree of stereo-

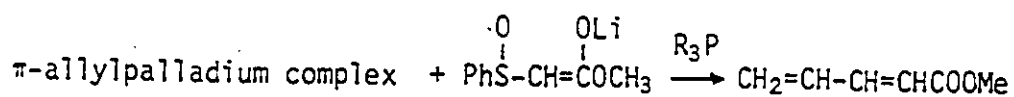


Figure 8. π -Allylpalladium Complexes in Alkylative Eliminations

selectivity and regioselectivity associated with this procedure, but a dienoate is the product of the reaction. Thus, simple alkylated dienes could not be synthesized by this method.

Dialkenylchloroboranes, available through the reaction of acetylenes with chloroborane-ethyl etherate, react rapidly to produce (E,E)-1,3-dienes in good yields²⁷. These results are summarized in Figure 9.

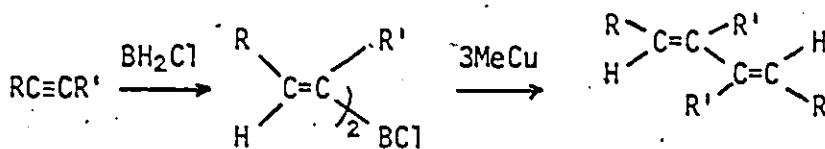


Figure 9. Methylcopper Induced Coupling of Dialkenylchloroboranes

The stereochemical purity of the product is greater than 99%, and the reaction can be extended to the accommodation of a functional group; however, since the procedure is, in essence, a coupling reaction, symmetrical dienes are produced. Vinylalanes²⁸ and vinyl Grignard reagents^{17,18,19} may also be coupled to form 1,3-dienes.

Another route to conjugated dienes was developed by Corey²⁰. This method, which is summarized in Figure 10, involves as a main feature the conjugate addition of vinyl organocopper reagents to α,β -acetylenic carbonyl compounds.

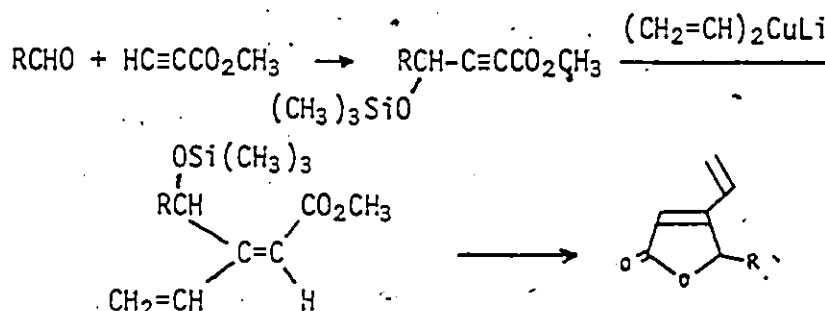
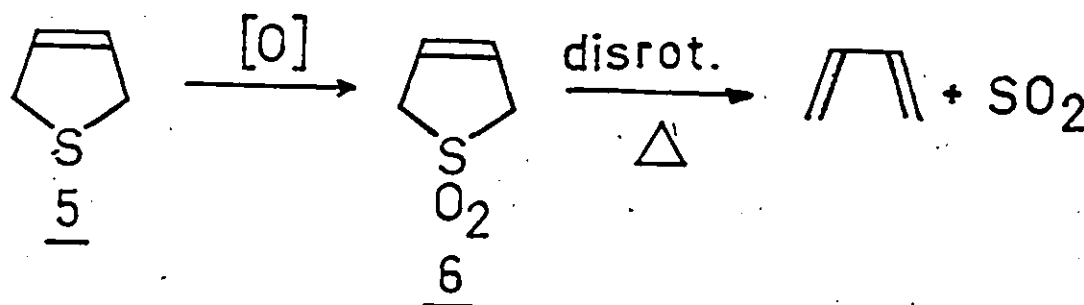


Figure 10. Synthesis of 1,3-Dienes via Organocopper Reagents

While some of the reactions are completely or partially regiospecific, the stereochemistry of the newly formed double bond is

in many cases difficult to predict. Lack of stability of many functional groups to the reaction conditions is also frequently encountered in these reactions. Therefore, the development of a new, versatile method for the formation of conjugated carbon double bonds under mild conditions and in a completely regiospecific and stereospecific manner would be desirable.

The thermal decomposition of 2,5-dihydrothiophene sulfones 6 to sulfur dioxide and conjugated dienes has frequently been used as the final step in the purification of diene mixtures and is used industrially to obtain diene monomers of very high purity²⁹. Woodward-Hoffmann rules³¹ predict that the thermal decomposition of 2,5-dihydrothiophene sulfones will be disrotatory in mode with complete retention of stereochemistry. These predictions have been confirmed experimentally and it has been shown that the reaction proceeds at easily accessible temperatures³⁰.



Compounds of type 6 are most easily made by the cheletropic addition³¹ of sulfur dioxide to a conjugated diene. This method of preparation clearly does not fit our requirements since the diene we hope to synthesize is required as a starting material. An alternate approach

to these types of compounds involves the oxidation of 2,5-dihydrothiophenes ³² 5. Thus, if a general procedure for the formation of 2,5-dihydrothiophenes could be developed, it would constitute an effective method for the preparation of conjugated dienes.

A survey of the literature related to the 2,5-dihydrothiophene ring system led us to a number of methods available for its synthesis. However, none of these can be described as a general procedure and all suffer serious drawbacks. The addition of sulfenyl chloride to a conjugated diene followed by the loss of the elements of chlorine has been shown by Trost ³³ to generate 2,5-dihydrothiophenes but in poor yield (Figure 11).

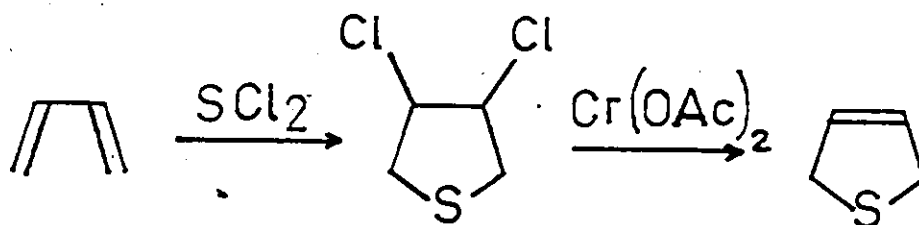


Figure 11. Trost's Synthesis of 2,5-Dihydrothiophenes

An alternative procedure was devised by Stotter ³⁴. The main feature of this method involves the Michael-type cyclization of a mercaptomuconate resulting in a 2,5-dihydro-2,4-disubstituted thiophene (Figure 12).

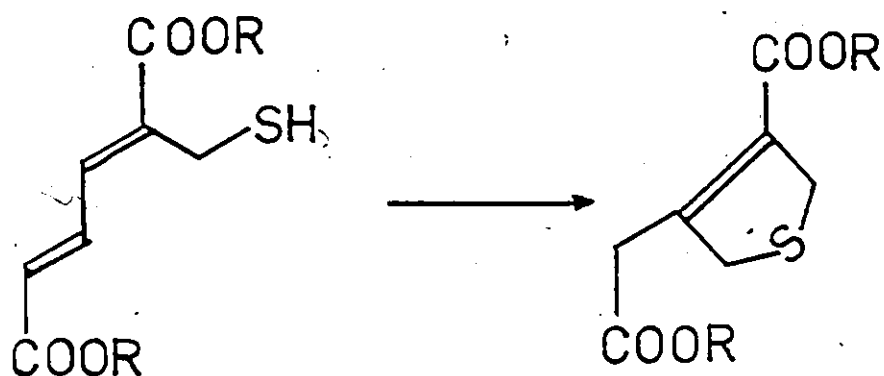


Figure 12. 2,5-Dihydrothiophenes by Mercaptomuconate cyclization

Both of these methods are clearly unsuited to our needs since the diene is required as a starting material. On the surface, it would appear that the most easily accessible route to 2,5-dihydrothiophenes is the partial reduction of the thiophene analogues. The partial reduction of thiophene has been effected with alkali metals in liquid ammonia^{32,35,36}. This method is very laborious and the results are unsatisfactory: 2,5-dihydrothiophene must be isolated either by careful fractional distillation³⁵ of a 1:2 mixture (ca. 40% yield) of the 2,3- and 2,5-dihydrothiophenes or by destruction of the 2,3-isomer by aqueous acid³⁶. In addition, geminally substituted materials are not available by this method. Recently, Brandsma³⁷ has shown that the parent compound, 2,5-dihydrothiophene, can be obtained in reasonable yield by reaction of cis-1,4-dichloro-2-butene with anhydrous sodium sulfide in a mixture of methanol and dimethyl

sulfoxide. Finally, Takaya³⁸ *et. al.* have prepared a limited number of 2,3,4-trisubstituted 2,5-dihydrothiophenes by the conjugate addition-cyclization sequence delineated in Figure 13. Again, this procedure

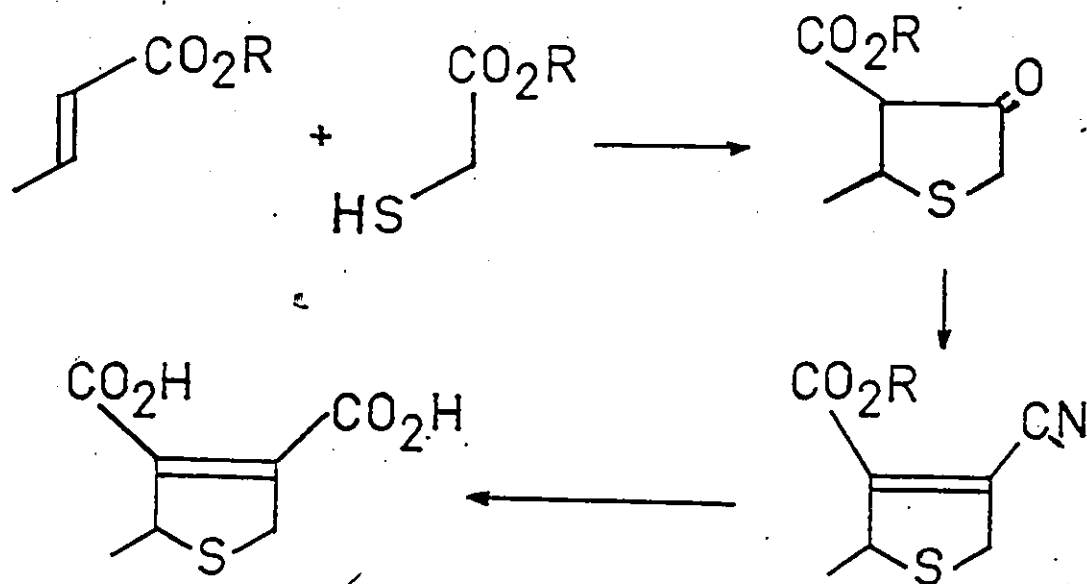


Figure 13. Synthesis of 2,3,4-Trisubstituted 2,5-Dihydrothiophenes

suffers from low yields and the substitution pattern is severely limited by the fact that one part of the molecule must be derived from a good Michael acceptor.

The synthetic utility of the 2,5-dihydrothiophene ring system has been demonstrated in other areas. Stork and Stotter³⁹ have shown that the olefinic bond in the ring when in conjugation with a carbonyl

function acts as a dienophile producing a thiabicyclo ring system. Reductive extrusion of sulfur from the intermediate with Raney nickel led to a stereospecific synthesis of trans-fused 8-methyl-1-hydrindanones 7. A summary of this reaction is depicted in Figure 14.

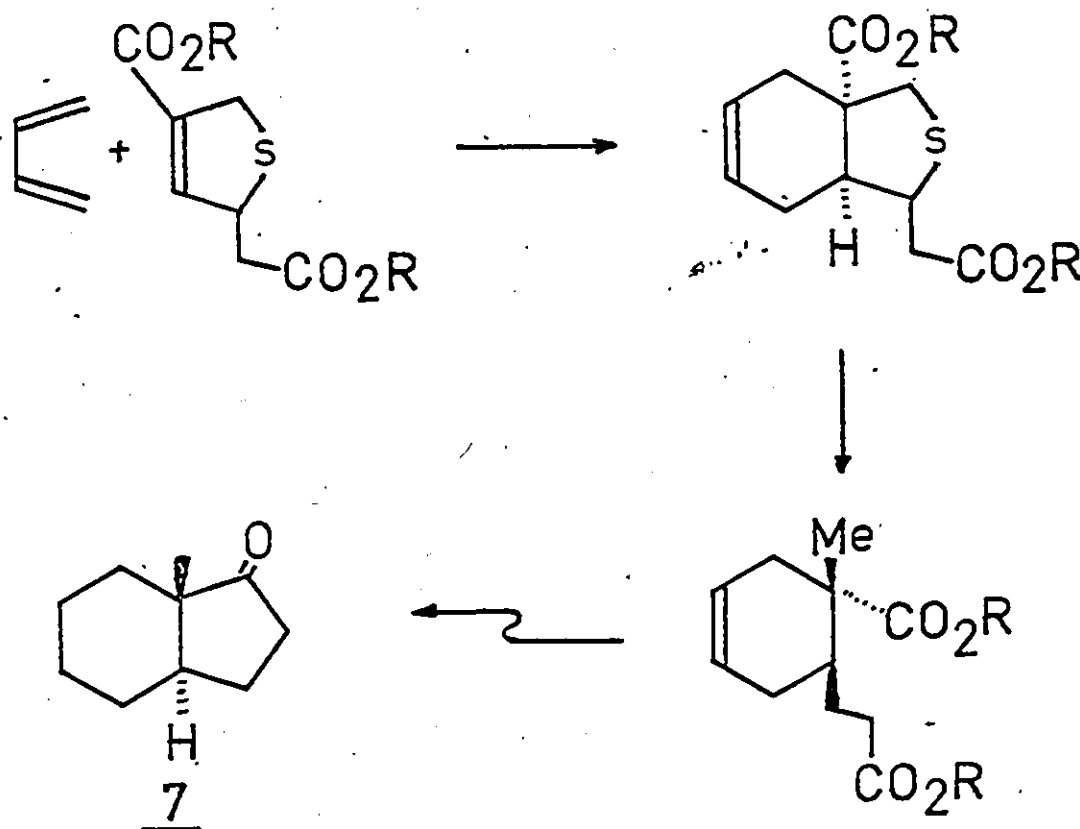


Figure 14. Synthetic Route to the 8-Methyl-1-Hydrindanone System

We have investigated the use of vinylphosphonium salts in the synthesis of 2,5-dihydrothiophenes⁴⁰. Keough and Grayson, in a study

carbonyl function was incorporated into the Michael donor, then the intermediate 9 (Figure 17), underwent an intramolecular Wittig reaction and a variety of useful carbocyclic and heterocyclic molecules could be obtained⁴⁴. Included in this group were 2,5-dihydrofurans and 2,5-dihydropyrroles^{44d}.

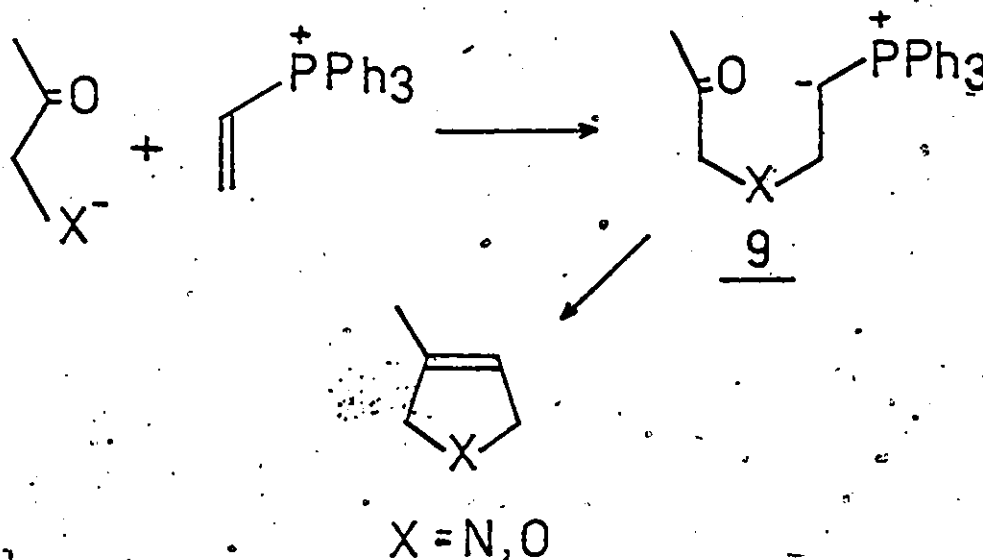


Figure 17. Schweizer's Heterocyclic Olefin Synthesis

Having this information in hand, it seemed clear that the reaction of α -mercaptocarbonyl compounds and vinylphosphonium salts should produce 2,5-dihydrothiophenes. Thus, our attention was focused on this reaction to generate the ring nucleus we deemed essential for the preparation of conjugated dienes.

RESULTS AND DISCUSSION

α -Mercaptocarbonyl compounds react with vinylphosphonium salts in generally excellent yield to afford a general synthesis of alkylated 2,5-dihydrothiophenes⁴⁰ (Figure 18, Table 3).

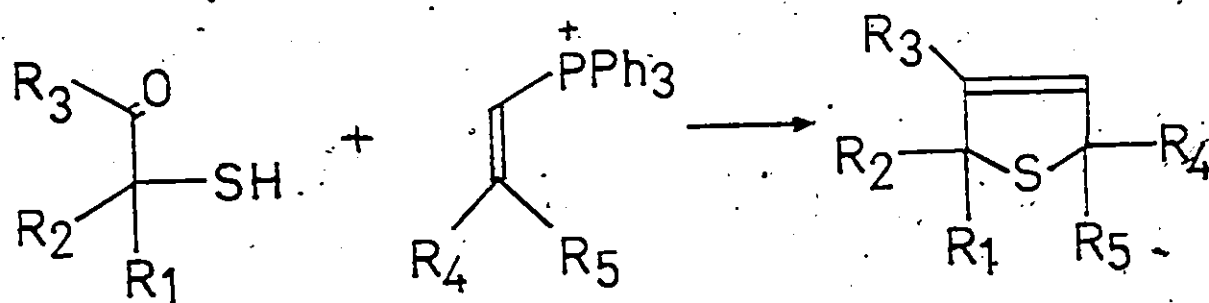


Figure 18. Synthesis of Alkylated 2,5-Dihydrothiophenes.

In a typical reaction, the primary allylic phosphonium salt, prepared from the corresponding allylic halide and triphenylphosphine, is stirred in pyridine containing an equivalent of triethyl amine for a short period of time. We have verified that under these conditions the allylic salts readily isomerize to their vinyl analogues as is shown by the rapid disappearance of the methylene absorption at δ 5-6 in the nmr spectrum. We have used this system to prepare vinyl salts 18 - 23 from their allylic analogues 18a - 23a (Table 2) in high yield. At this point the appropriate α -mercaptocarbonyl compound is added (Table 1). We have found that under these conditions the mercaptide anion reacts smoothly in a Michael-Wittig sequence to yield the alkylated 2,5-dihydrothiophene

TABLE 1

 α -Mercaptocarbonyl Compounds

<u>Compound</u>	<u>R₁</u>	<u>R₂</u>	<u>R₃</u>
<u>10</u>	Me	Me	Me
<u>11</u>	H	— (CH ₂) ₄ —	
<u>12</u>	Me	Me	<u>i</u> -Pr
<u>13</u>	Me	H	H
<u>14</u>	Et	H	H
<u>15</u>	Me	H	Me
<u>16</u>	Me	H	Et
<u>17</u>	H	Ph	Me

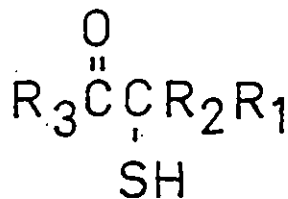


TABLE 2

Vinylphosphonium Salts

<u>Compound</u>	<u>R₄</u>	<u>R₅</u>
<u>18</u>	H	H
<u>19</u>	Me	H
<u>20</u>	Me	Me
<u>21</u>	Et	H
<u>22</u>	<u>i</u> -Pr	H

The corresponding allyl isomers are given the subscript a.

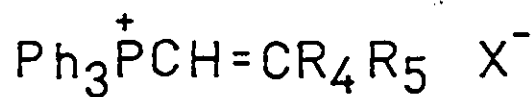


TABLE 3 - Products and Yields of 2,5-Dihydrothiophenes^a

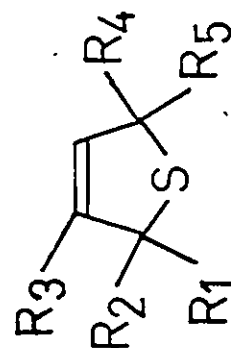
<u>Mercaptan</u>	<u>Salt</u>	<u>Product</u>	<u>R₁</u>	<u>R₂</u>	<u>R₃</u>	<u>R₄</u>	<u>R₅</u>	<u>Time (hr.)</u>	<u>Yield (%)</u>
<u>10</u>	<u>18</u>	<u>24</u>	Me	Me	Me	H	H	30	95
<u>10</u>	<u>19</u>	<u>25</u>	Me	Me	Me	Me	H	20	80
<u>10</u>	<u>20</u>	<u>26</u>	Me	Me	Me	Me	Me	30	30
<u>11</u>	<u>18</u>	<u>27</u>	H	-(CH ₂) ₄ -	-(CH ₂) ₄ -	H	H	18	75
<u>11</u>	<u>19</u>	<u>28</u>	H	-(CH ₂) ₄ -	-(CH ₂) ₄ -	Me	H	18	91
<u>11</u>	<u>21</u>	<u>29</u>	H	-(CH ₂) ₄ -	-(CH ₂) ₄ -	Et	H	42	88
<u>11</u>	<u>20</u>	<u>30</u>	H	-(CH ₂) ₄ -	-(CH ₂) ₄ -	Me	Me	55	61

TABLE 3 (cont'd) - Products and Yields of 2,5-Dihydrothiophenes^a

<u>Mercaptan</u>	<u>Salt</u>	<u>Product</u>	<u>R₁</u>	<u>R₂</u>	<u>R₃</u>	<u>R₄</u>	<u>R₅</u>	<u>Time (hr.)</u>	<u>Yield (%)</u>
<u>12</u>	<u>18</u>	<u>31</u>	Me	Me	i-Pr	H	H	48	20
<u>12</u>	<u>19</u>	<u>32</u>	Me	Me	i-Pr	Me	H	72	6
<u>13</u>	<u>19</u>	<u>33</u>	Me	H	H	Me	H	18	32
<u>14</u>	<u>19</u>	<u>34</u>	Et	H	H	Me	H	2	70
<u>14</u>	<u>22</u>	<u>35</u>	Et	H	H	i-Pr	H	3	50
<u>15</u>	<u>19</u>	<u>36</u>	Me	H	Me	Me	H	18	78
<u>15</u>	<u>21</u>	<u>37</u>	Me	H	Me	Et	H	18	60

TABLE 3 (cont'd) - Products and Yields of 2,5-Dithydrothiophenes^a

<u>Mercaptan</u>	<u>Salt</u>	<u>Product</u>	<u>R₁</u>	<u>R₂</u>	<u>R₃</u>	<u>R₄</u>	<u>R₅</u>	<u>Time (hr.)</u>	<u>Yield (%)</u>
<u>16</u>	<u>19</u>	<u>38</u>	Me	H	Et	Me	H	18	80
<u>16</u>	<u>21</u>	<u>39</u>	Me	H	Et	Et	H	18	64
<u>16</u>	<u>22</u>	<u>40</u>	Me	H	Et	i-Pr	H	18	64
<u>17</u>	<u>18</u>	<u>41</u>	H	Ph	Me	H	H	168	65



a) see Figure 18.

TABLE 4 - Indices of Refraction and Nmr Spectra

<u>Compound</u>	<u>$n_D(\text{temp.}, ^\circ\text{C})$</u>	<u>Nmr Spectral Data^a</u>
<u>24</u>	1.4912 (25)	5.32 (m,1), 3.60 (t,2,J=2), 1.72 (d,3,J=1.5), 1.51 (s,6).
<u>25</u>	1.4860 (25)	5.22 (m,1), 4.02 (m,1), 1.69 (t,3,J=2), 1.50 (s,3), 1.47 (s,3), 1.35 (d,3,J=6).
<u>26</u>	1.4701 (25)	5.15 (d,1,J=1), 1.67 (d,3,J=1), 1.50 (s,12).
<u>27</u>	1.5476 (25)	5.35 (m,1), 3.70 (m,3), 2.80-1.01 (m,8).
<u>28</u>	1.5272 (25)	5.26 (d,1,J=2), 4.48-3.70 (m,2), 2.72-1.10 (m,8), 1.40 (d,3,J=6.5).
<u>29</u>	1.5221 (20)	5.25 (d,1,J=2), 4.3-3.7 (m,2), 2.80-1.15 (m,10), 1.00 (t,3,J=6).
<u>30</u>	1.5129 (25)	5.10 (t,1,J=1.5), 3.70 (m,1), 2.65-1.10 (m,8), 1.48 (s,3), 1.44 (s,3).
<u>31</u>	1.4732 (25)	5.40 (t,1,J=2), 3.53 (d,2,J=2), 2.22 (m,1), 1.45 (s,3), 1.12 (d,6,J=7).

a) Spectra run in CDCl_3 . b) insufficient sample. c) sample contaminated by thiophene.

TABLE 4 (cont'd) - Indices of Refraction and Nmr Spectra

<u>Compound</u>	<u>$n_D(\text{temp.}, ^\circ\text{C})$</u>	<u>Nmr Spectral Data^a</u>
<u>32</u>	b	5.23 (d,1,J=2), 3.99 (m,1), 2.13 (m,1), 1.45 (s,3), 1.41 (s,3), 1.27 (d,3,J=7), 1.07 (d,6,J=7).
<u>35</u>	c	5.75 (s,2), 4.4-3.9 (m,2), 2.10-1.35 (m,3), 1.0 (t,3,J=7), 0.97 (d,6,J=7.5).
<u>36</u>	1.5291 (25)	5.37 (d,1,J=2), 4.4-3.8 (m,2), 1.8 (d,3,J=0.5), 1.46 (d,3,J=7), 1.42 (d,3,J=7).
<u>37</u>	1.4930 (20)	5.32 (d,1,J=2), 4.25-3.5 (m,2), 2.0-1.5 (m,2), 1.78 (d,3,J=0.5), 1.37 (d,3,J=7), 1.0 (t,3,J=6.5).
<u>38</u>	1.4910 (25)	5.5 (s,1), 4.55-3.95 (m,2), 2.6-1.8 (m,2), 1.46 (d,3,J=7.5), 1.42 (d,3,J=7.5), 1.12 (t,3,J=9).
<u>39</u>	1.4921 (25)	5.52 (s,1), 4.5-3.9 (m,2), 2.5-1.6 (m,4), 1.48 (d,3,J=7.5), 1.16 (t,3,J=8), 1.01 (t,3,J=8).
<u>40</u>	1.5062 (20)	5.37 (d,1,J=1.5), 4.4-3.8 (m,2), 2.7-1.5 (m,3), 1.39 (d,3,J=7), 1.10 (t,3,J=8), 0.96 (d,6,J=8).
<u>41</u>	1.5186 (25)	7.12 (s,5), 5.50 (m,1), 4.85 (m,1), 3.71 (m,2), 1.51 (m,3).

TABLE 5 - Analytical Data

<u>Compound</u>	<u>Calculated</u>			<u>Found</u>		
	<u>C</u>	<u>H</u>	<u>S</u>	<u>C</u>	<u>H</u>	<u>S</u>
<u>24</u>	65.60	9.44	24.97	65.67	9.55	24.21
<u>25</u>	67.57	9.92	22.50	69.35	10.18	20.86 ^a
<u>26</u>	69.19	10.32	20.48	69.32	10.51	20.25
<u>27</u>	68.55	8.63	22.83	68.68	8.74	22.82
<u>28</u>	70.10	9.15	20.75	69.92	9.16	20.59
<u>29</u>	71.37	9.58		71.32	9.24	
<u>30</u>	71.37	9.58	19.04	71.27	9.71	19.02
<u>31</u>	69.19	10.32	20.48	69.28	10.96	19.70
<u>32</u>	70.55	10.66		70.64	10.81	
<u>33</u>		reference 28				
<u>34</u>		reference 35c				

TABLE 5 (cont'd) - Analytical Data

Compound	Calculated			Found		
	C	H	S	C	H	S
<u>35^b</u>						
<u>36</u>		m/e=128.06597			m/e=128.06534	
<u>37</u>	67.57	9.92		67.80	10.01	
<u>38</u>	67.57	9.92		67.12	9.67	
<u>39</u>	69.19	10.31		69.26	10.24	
<u>40</u>		m/e=170.11292			m/e=170.11192	
<u>41</u>	74.98	6.86	18.16	75.14	6.94	18.09
						24

a) The high resolution mass spectrum of this compound exhibited the correct m/e parent ion of 142.

b) sample contaminated with thiophene.

TABLE 6 - Carbon-13 Nmr Shifts of 2,5-Dihydrothiophenes^a

Compound	C ₂	C ₃	C ₄	C ₅	R ₂	R ₃	R ₅
5 ^b	39.1	128.8	128.8	39.1	-	-	-
36	52.0	141.3	129.1	47.7	28.8	14.8	25.4
25	60.3	144.8	128.0	45.4	30.8	12.4	24.8
					31.9		
cis-37	51.2	-	127.0	55.4	23.6	15.0	32.0(CH ₂) 12.0(CH ₃)
trans-37	51.0	-	127.0	55.0	22.7	15.0	31.4(CH ₂) 11.8(CH ₃)
					ring C		
27	54.3	145.0	118.6	37.5	38.7, 29.8		-
					27.3, 26.2		
28	54.9	143.7	125.5	48.3	39.7, 29.7		25.4
					27.4, 25.8		
30	54.3	141.3	130.7	58.2	39.1, 29.6		33.6
					27.3, 25.9		33.0

a) Chemical shifts reported downfield from TMS. b) reference 37.

(Table 3). Indices of refraction, spectral data and analytical data are shown in Table 4 and 5. The carbon-13 spectra of some alkylated 2,5-dihydrothiophenes⁴¹ are found in Table 6. The ultraviolet spectra showed that the 2,5-dihydrothiophenes possess a common chromophore: $\lambda_{\text{max}}(\text{CH}_3\text{CN})$ 230-234 ($\epsilon=200-400$).

It should be noted that several groups have commented on the lack of addition of alcohols and amines to β -substituted vinylphosphonium salts^{42,45,46}. However, one publication⁴⁵ indicated that the more nucleophilic mercaptans⁴⁷ would add to salt 19 in the presence of a catalytic amount of base. We have found that β -substitution on the vinylphosphonium salts has little effect on the yield of the 2,5-dihydrothiophenes.

We were intrigued by the report⁴⁸ of the isolation of the vinyl salt 19 ($X=\text{Cl}$) when allyl chloride and triphenylphosphine were heated together in benzene, while the use of allyl bromide led to the expected allyl salt 19a. We have found that the same situation applies when methallyl chloride is used under equivalent conditions. The vinyl salt obtained has the same physical properties as those reported⁴⁹ for the expected allyl salt 20a, although the nmr spectrum clearly indicates the structure 20 (δ 6.48). Thus, the earlier report is in error. In analogy with the previous report⁴⁸, when a large excess of methallyl chloride is heated in the presence of the phosphine in the absence of added solvent, a 5:1 mixture (nmr) of the allyl:vinyl salts were obtained. The suggestion has been made that the increased nucleophilicity of chloride relative to bromide ion was responsible for this result⁴⁸. We have found that refluxing a benzene slurry of the bromide salt 19a with lithium chloride effects

complete isomerization (nmr) into the vinyl salt 19 but, in view of the base-catalyzed isomerization reported above, we prefer to attribute this result to the difference in basicity of the two halide ions. Other workers have reported the isolation of vinyl salts from reactions of allylic halides⁵⁰.

In order to attain generality for the synthesis, a reliable preparation of α -mercaptocarbonyl compounds and their α -halo precursors must be used. The methods available for the regiospecific halogenation of carbonyl compounds have been reviewed⁵¹ and a procedure involving the N-bromosuccinimide halogenation of enol borinates⁵² seems to offer highly regiospecific synthesis for this type of compound. Replacement of the halogen by a sulfhydryl group proved to be a facile reaction. The stereochemistry, unlike the regiochemistry, is unimportant since the eventual fate of the carbon atom bearing this substituent is sp^2 hybridization and thus destroying any stereochemistry.

The α -mercaptocarbonyl compounds typically exist as dimeric dihydroxy-1,4-dithianes, 42^{53,54}, many of which are highly insoluble in the usual organic solvents and which are easily dehydrated by traces of acid to transannular ethers 43^{53,2} (Figure 19). In basic solution, an equilibrium is set up between monomer and dimer and the material becomes much more soluble⁵⁴. Our initial attempts to synthesize a dihydrothiophene followed Schweizer's methodology closely: that is, sodium hydride in tetrahydrofuran was used to generate the mercaptide anion and dimethyl formamide was employed as a cosolvent in an effort to improve the solubilities of the reactants. However, this led to a tedious workup procedure consisting of repeated triturations with pentane to separate

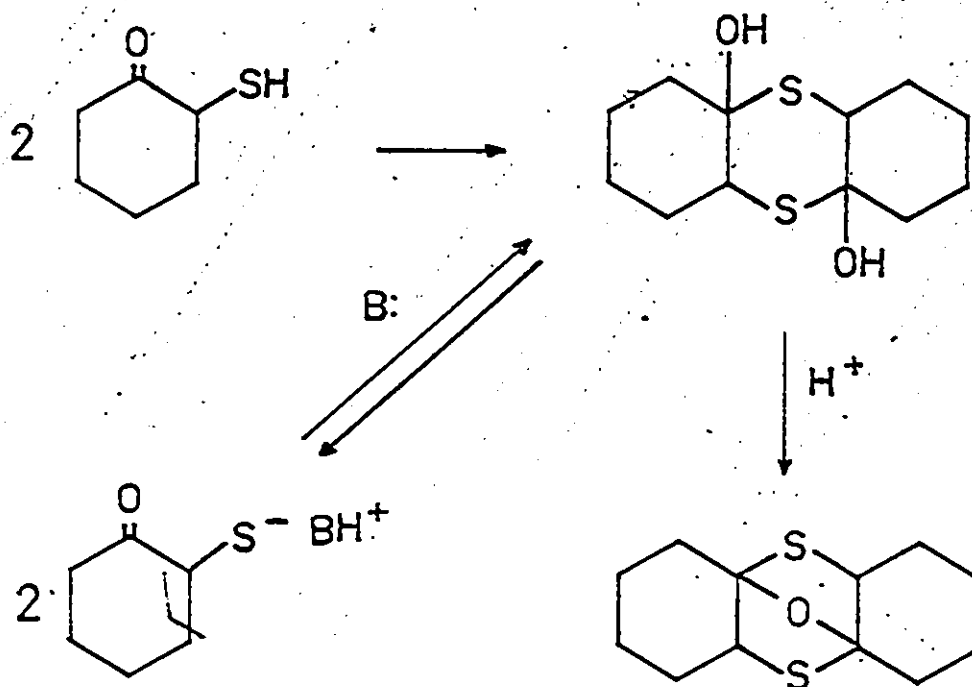


Figure 19. Dimerization of α -Mercaptoketone 11

the dihydrothiophene. As a result of this laborious workup procedure, the yield of the dihydrothiophene suffered. The ability of pyridine to dissolve both reactants, serve as the base, and provide a solvent which could easily be removed by acid extraction made its use ideal. While some reactions did proceed well with only pyridine as the solvent, the addition of an equivalent of triethyl amine accelerated the reaction and also effected the isomerization of the allylic salts to their vinyl analogues in situ. Simple filtration through acidic alumina eliminated all phosphorus containing and coloured impurities and afforded the 2,5-dihydrothiophene listed in Table 3 in the generally excellent yields shown.

Several additional comments about this reaction are required. We have found that superior results are obtained with the use of

undistilled α -mercaptocarbonyl compounds, especially in the case of α -mercaptoaldehydes. Distillation of these materials invariably leads to dehydration of their dimeric form and thus diminution in the yield of the dihydrothiophene. In addition, in several reactions when α -mercaptoaldehydes were utilized, the nmr spectrum of the chromatographed product showed the presence of a thiophene ($\delta=6.5-7.0$). Since the reactions were carried out under a blanket of nitrogen, it is unlikely that aerial oxidation of these compounds occurs. Disproportionation also can be ruled out as no trace of the corresponding tetrahydrothiophene could be detected. At this time, we have no explanation for this result.

Anomalous results were obtained when the salt 23 was reacted with ketones 10 and 11. In the first case, the product 44 was derived by attack of the thiolate anion on the equilibrium concentration of the allylic isomer of the salt (Figure 20). We envisage that the increased steric bulk at the carbon atom β to phosphorus must preclude the reaction of the nucleophile at that point. Substitution, with or without allylic rearrangement, will lead to the observed product.

The product isolated in high yield from the reaction of 23 and 11 was identified as α -methylstyrene. This may be formed by the attack of sulfur at phosphorus, but we have no evidence for this at the present time. Finally, when the α -mercaptoketone 17 was used, an additional peak in the glc appeared and was identified as phenylacetone, a product of desulfurization of 17. Desulfurization of aromatic mercaptoketones under basic conditions also has been observed by other workers⁵⁵.

The synthetic utility of the 2,5-dihydrothiophenes in the formation of conjugated dienes is illustrated by the Figure 21⁶². When

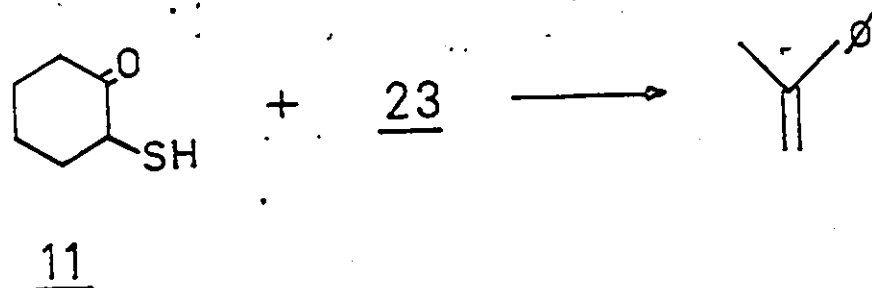
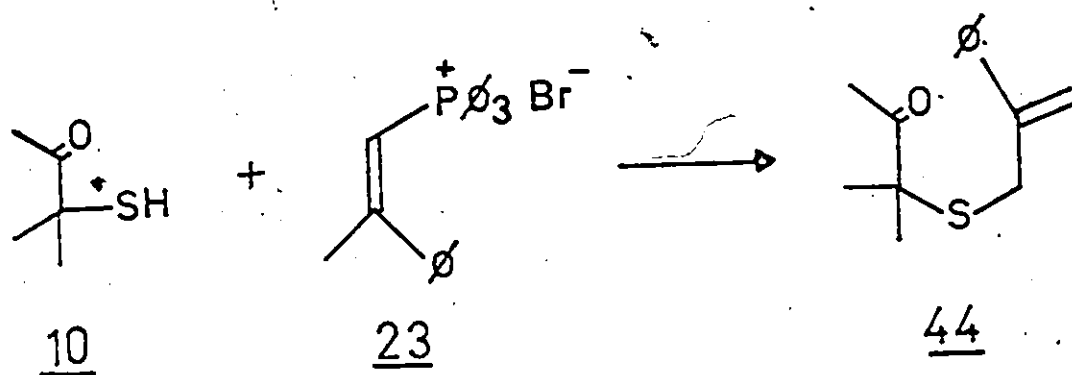


Figure 20. Anomalous results using Salt 23

the mercaptan derived from methyl isopropyl ketone 10 is treated with 18 and the resulting 2,5-dihydrothiophene is oxidized with two equivalents of *m*-chloroperbenzoic acid, thermolysis of the resulting sulfone 45 leads to the diene 3,4-dimethyl-1,3-pentadiene 47. Diels-Alder reaction with the diene and maleic anhydride proceeds smoothly to form 46. The unambiguous formation of 47 from mercaptan 10 occurs in an overall 74% yield in three simple steps. The only previous synthesis of the diene 47 involved a multi-step reaction sequence starting from a complex starting material and proceeding in an 8% overall yield⁵⁶.

Although the ultimate goal of this project was the development

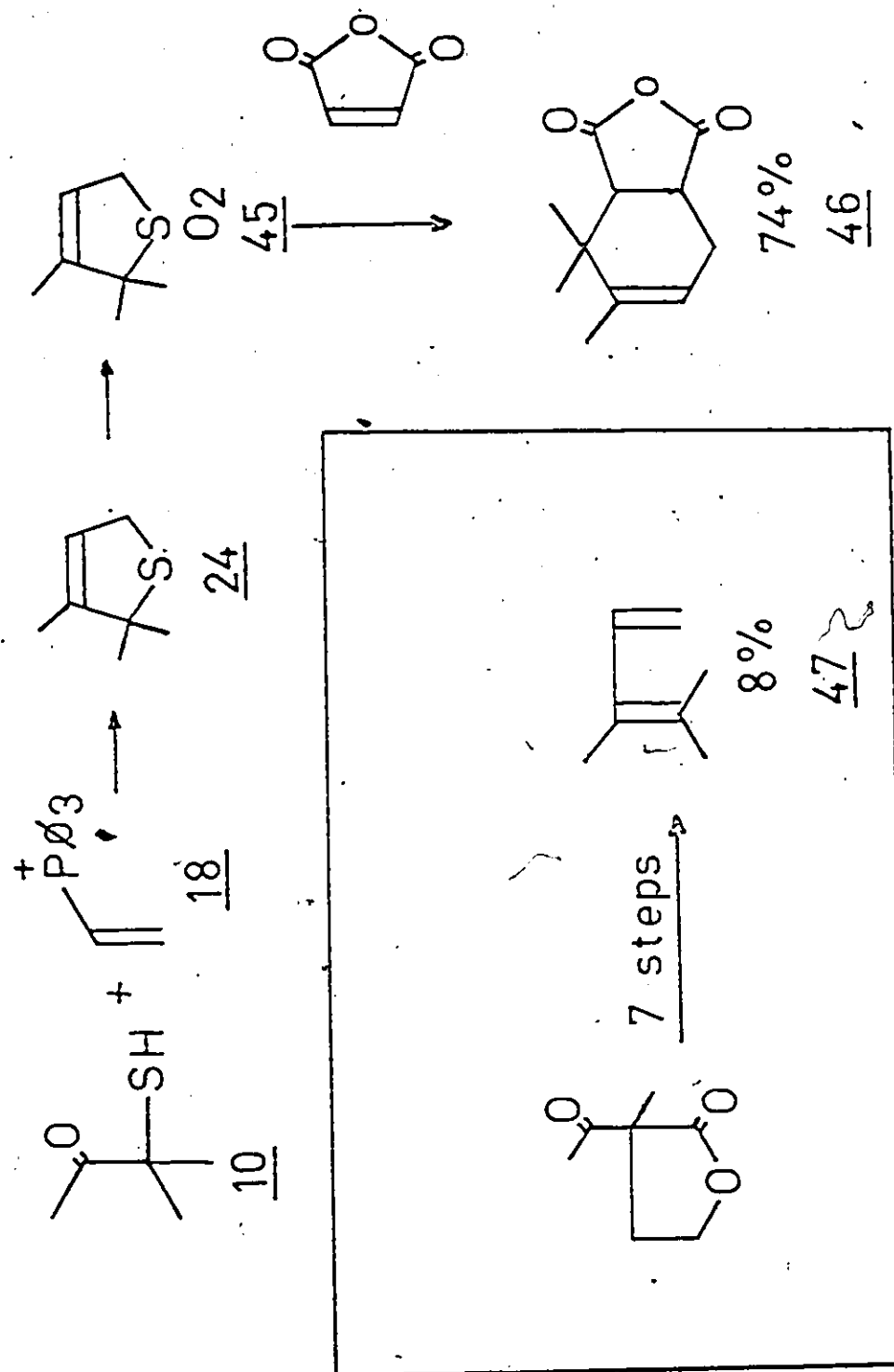


Figure 21. 2,5-Dihydrothiophenes as Latent Dienes⁶².

of a general procedure for the regio- and stereospecific synthesis of conjugated dienes, our interest in these compounds extends further (Figure 22). We have shown that the total reduction of the dihydrothiophene nucleus with Raney nickel⁶³ will lead to a synthesis of highly substituted alkanes⁵⁷. Oxidation of the nucleus with chloranil-pyridine allows a general synthesis of alkylated thiophenes⁵⁸. Currently a project is underway to investigate the possibility of a stereospecific cis-olefin synthesis via the reductive extrusion of the sulfur atom from the dihydrothiophene ring⁵⁹. Oxidation of the ring with peracid leads to the sulfone usually in quantitative yield. While thermolysis of the sulfone leads to dienes, alteration of the sulfone nucleus by reaction with nitrenes, peracids or carbenes permits the formation of divinyl amines⁶⁰, divinyl ethers⁶¹ or 1,4-dienes⁶², respectively. The scope of these reactions has been limited by the inaccessibility of the 2,5-dihydrothiophenes. Thus, our route to these compounds, not dependent on dienes as a starting material, should significantly increase their utility. We have also demonstrated that our reaction sequence can lead to functionalized dienes⁶⁴.

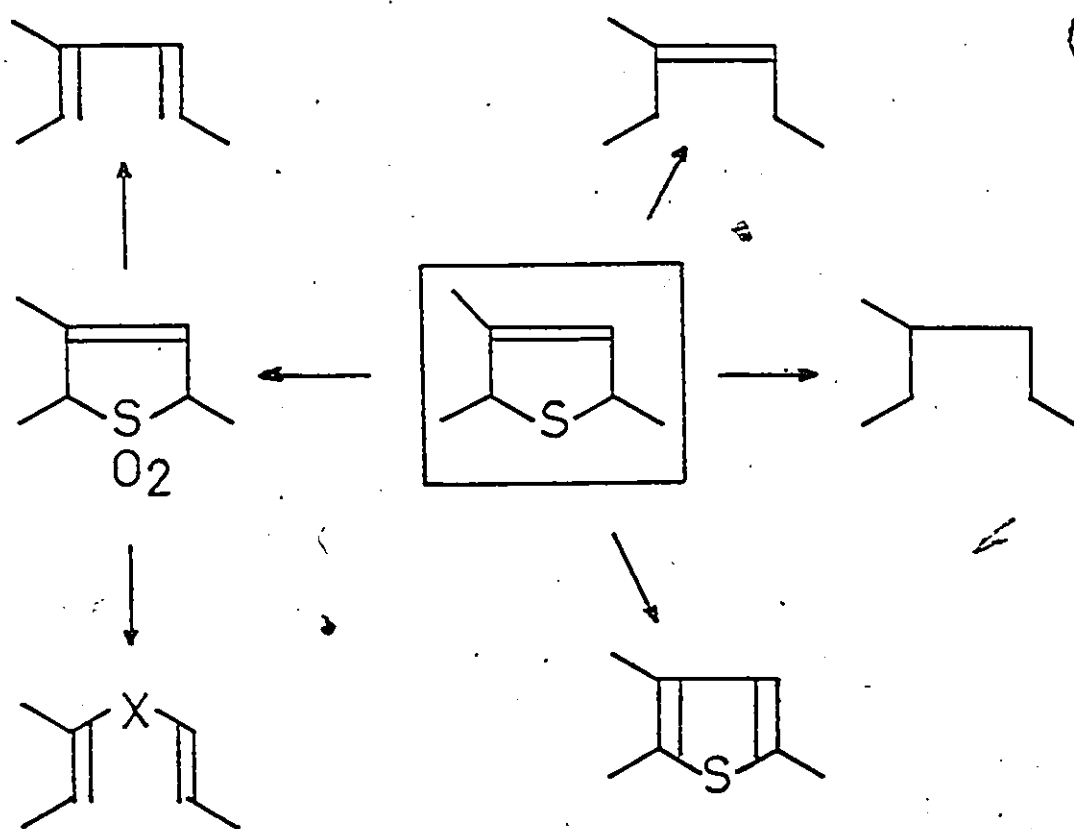


Figure 22. Extensions of the Dihydrothiophene Nucleus

CHAPTER 2THE STEREOCHEMISTRY OF DIHYDROTHIOPHENE AND DIENE FORMATIONINTRODUCTION

One of the most active areas in organic synthesis in the past decade has been the development of methods for construction of unsaturated compounds in stereoselective and stereospecific ways. Application of the Diels-Alder reaction to stereospecific organic synthesis has been severely hampered by the fact that a good, general, stereoselective synthesis of conjugated dienes has not been reported.

One method of 1,3-diene synthesis which has been shown to be stereospecific is the thermal decomposition of 2,5-dihydrothiophene sulfones which occurs in a completely regiospecific and stereospecific disrotatory manner^{30,65,76}. In Chapter 1, we presented a new and facile preparation of 2,5-dihydrothiophenes and showed that they could be converted to conjugated dienes through the intermediacy of the corresponding sulfone. In view of the importance of this diene synthesis, we attempted an investigation of the stereochemistry both of the initially formed 2,5-dihydrothiophenes and also the dienes⁶⁶.

Some of the most important present day concepts concerning the states and geometries of molecules have come from consideration of the symmetry of molecular orbitals. Examples include the orbital correlation

diagrams of Mulliken⁶⁷ and Walsh⁶⁸ to explain the electronic structure of diatomic and polyatomic molecules and by Woodward and Hoffmann³¹ to develop selection rules for chemical reactions. Briefly, those rules explain that in a concerted reaction, the lowest energy pathway, and therefore the course of the reaction, will involve the route where orbital symmetry is conserved. Although the thermal decomposition of dihydrothiophene sulfone is disrotatory, this mode is reversed in the excited state and the photochemical decomposition of these sulfones follows a conrotatory elimination of sulfur dioxide^{31,65}. Thus, photochemical decomposition of the sulfones occurs in the opposite stereochemical sense and allows stereoselective formation of either of two diene isomers, depending on whether the elimination was thermochemical or photochemical⁶⁵. The common philosophy is that if a given reaction leads to only one of several geometrical isomers, all of which are accessible through stereochemically acceptable transition states, and if the isomer formed is that predicted by orbital symmetry factors, this can be considered ipso facto as evidence for orbital symmetry control⁶⁹. We offer here descriptive stereochemical aspects of 2,5-dihydrothiophene formation and the thermochemistry of the corresponding sulfones.

RESULTS

A. SEPARATION OF THE DIHYDROTHIOPHENES

Initially, we were unable to detect any indication of the presence of two dihydrothiophene isomers using gas chromatography. However, by utilizing a very polar column and low temperatures⁷⁰, we finally achieved separation of the isomers in some cases. In each case the order of elution was trans- followed by cis-2,5-dialkyl-2,5-dihydrothiophene, as was shown by the ratios of the dienes subsequently obtained (vide post). Unfortunately, in cases where the nmr spectra showed the presence of the corresponding thiophene as an impurity, separation of the isomers and therefore the cis/trans ratio of the dihydrothiophene could not be recorded. Delineation of the various product distributions resulting from our glc analysis are found in Table 7.

B. PREPARATION AND DECOMPOSITION OF THE SULFONES

As already discussed, the thermal elimination of sulfur dioxide from the sulfones is a stereospecific disrotatory process and therefore the stereochemistry of the dienes obtained faithfully reflects that of the dihydrothiophenes from which they were derived. Specifically, cis-5 leads to (E,E)- or (Z,Z)-diene whereas trans-5 leads to (E,Z)- or (Z,E)-diene on oxidation and pyrolysis. Therefore, isomeric analysis of the dienes also affords the cis/trans ratio of the dihydrothiophenes and gives a check on the direct glc analysis.

One problem foreseen was the rearrangement of the dienes by

TABLE 7

Isomeric Distribution of Dihydrothiophene and Diene Mixtures^a

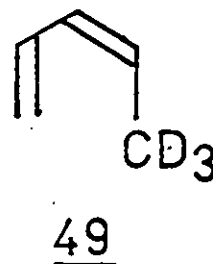
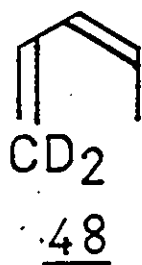
<u>Dihydrothiophene</u>	<u>Glc Analysis</u> <u>cis: trans (%)</u>	<u>Sulfone Pyrolysis</u> <u>(E,E+Z,Z) : (E,Z+Z,E) (%)</u>
<u>33</u>	_____	92:8
<u>34</u>	83:17	81:19
<u>35</u>	_____ ^b	75:25
<u>36</u>	79:21	79:21
<u>37</u>	67:33	69:31
<u>38</u>	78:22	_____ ^c
<u>39</u>	78:22	_____ ^c
<u>40</u>	54:46	57:43
<u>28</u>	_____	96:4
<u>29</u>	_____	96:4

a) see experimental for glc conditions.

b) direct determination impossible due to thiophene contamination

c) separation of isomers not achieved.

1,5-hydrogen transfer^{49a,65,71}. Specific thermal [1,5] sigmatropic rearrangements have been observed in a great number of cases⁷². The simplest case of a 1,3-pentadiene was studied by Roth⁷³. He compared the rearrangement of 48 and 49, and observed a large kinetic isotope effect of 12.2 kcal/mole at 25⁰ C, consistent with a highly symmetrical transition state in a concerted process. The activation for the rearrangement was in the vicinity of 35 kcal/mole. We chose to effect the pyrolysis of the sulfones in the injection part of the gas chromatograph to minimize the pyrolysis time and thus the chance for rearrangement. Effecting the pyrolysis in this manner, we have failed to detect a rearranged diene in any of the cases studied. However, when the pyrolysis of 45 was carried out in



refluxing xylene in the presence of maleic anhydride, the product obtained was derived from the rearranged diene⁷⁷. This reaction can be minimized by carrying out the reaction in toluene⁷⁷.

The dihydrothiophenes were oxidized to the sulfones using two equivalents of m-chloroperbenzoic acid and were immediately decomposed by injection into the glc. In every case, the only products observed

were sulfur dioxide and a diene mixture. The results of the diene analysis are incorporated into Table 7. Where possible, the dienes were collected separately and identified by their spectra.

In several cases, (38, 39, 40) separation on a preparative scale was not feasible and then the nmr spectrum of the diene mixture served to identify the major component and glc analysis gave the (E,E)/(E,Z) ratio. In the case of 28, because of the extremely heavy bias of the diene mixture, authentic samples were prepared and compared to the pyrolysis products.

Inspection of Table 7 shows that, in all cases, cis-5 is favoured over the trans isomer, but incorporation of increasingly bulky groups as ring substituents leads to an increase in the amount of trans isomer present.

DISCUSSION

The accepted mechanism for the cyclization reaction involves the conjugate addition of the thiolate anion to the polarized double bond of the phosphonium salt, followed by an intramolecular Wittig reaction of the ylide so formed^{40b} (Figure 23). The first step of this sequence is known to be reversible⁷⁴. Assuming irreversible betaine decomposition⁷⁵,

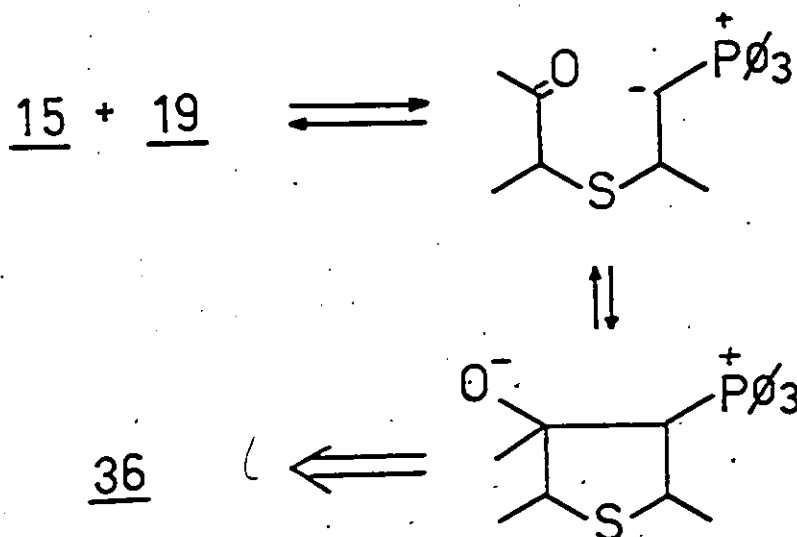


Figure 23. Mechanism of Dihydrothiophene Formation

the product stereochemistry will be determined by structural influences on the transition state for this step. Models suggest that the ring is nearly planar at this point with substantial eclipsing of all substituents. Thus, it is clear that in order to minimize serious steric interactions, substituents at C-2 and C-5 (Figure 24) must be trans to the phosphorus

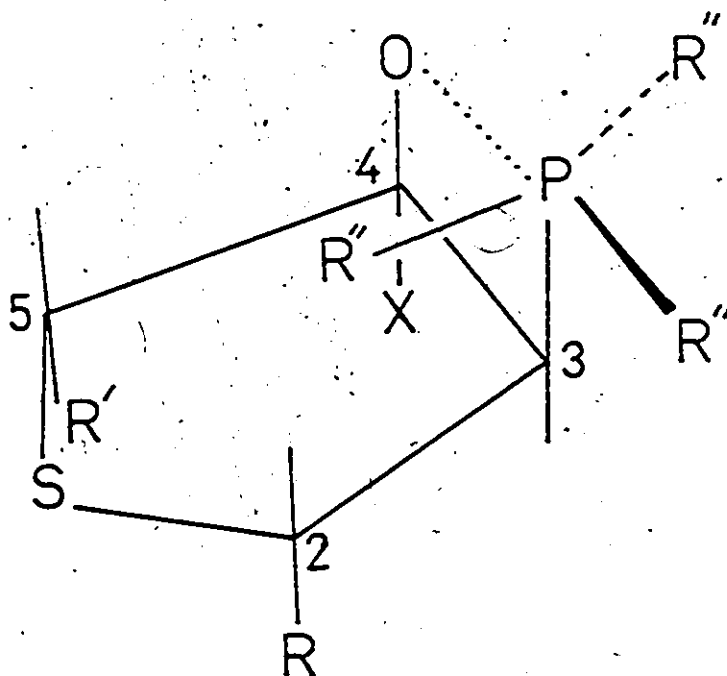


Figure 24. Stereochemical Model for Dihydrothiophene Formation *

* For a comprehensive review on the conformations of 5-membered rings see:
 N: L. Allinger, E. L. Eliel, "Topics in Stereochemistry", Vol. 4, Wiley-Interscience, 1970.

atom, thus favoring formation of the cis-2,5-dialkyl-2,5-dihydrothiophene. A result of this analysis is the prediction that this steric discrimination should decrease as the steric bulk of R, R' and X increase. Inspection of Table 7 bears this out and lends support to this rationale.

Although in theory four diene isomers (E,E; Z,Z; E,Z; Z,E) are isolable from the pyrolysis of the sulfones, in actuality only two appear to be found. A model was devised which appears to account for this result.

From the cis-2,5-dihydrothiophene sulfones, there are two disrotatory modes available for the thermolysis, leading to (E,E)- and (Z,Z)-dienes as depicted in Figure 25. It is clear from models of these compounds, that, in the case where R and R' rotate towards each other, steric problems are encountered. Thus, pyrolysis of the sulfone follows

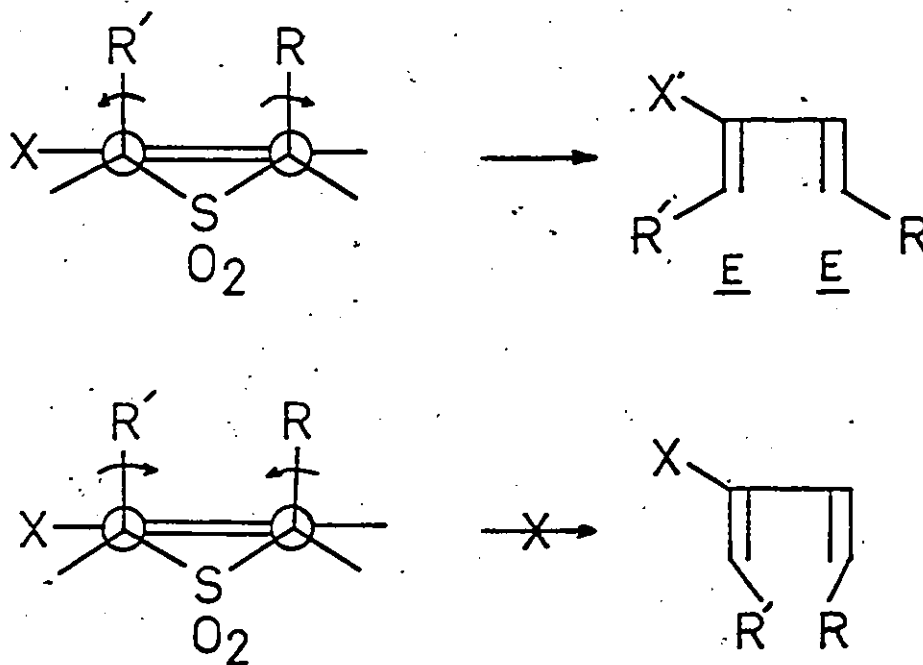


Figure 25. Pyrolysis of cis-Sulfones

the other, more favourable, path and the (E,E)-diene is the only isomer isolated. A similar argument has been invoked to explain the fragmentation of the 3-thiabicyclo [3.1.0.] hexane 3,3-dioxide ring system to 1,4-diene (Figure 26)⁶¹.

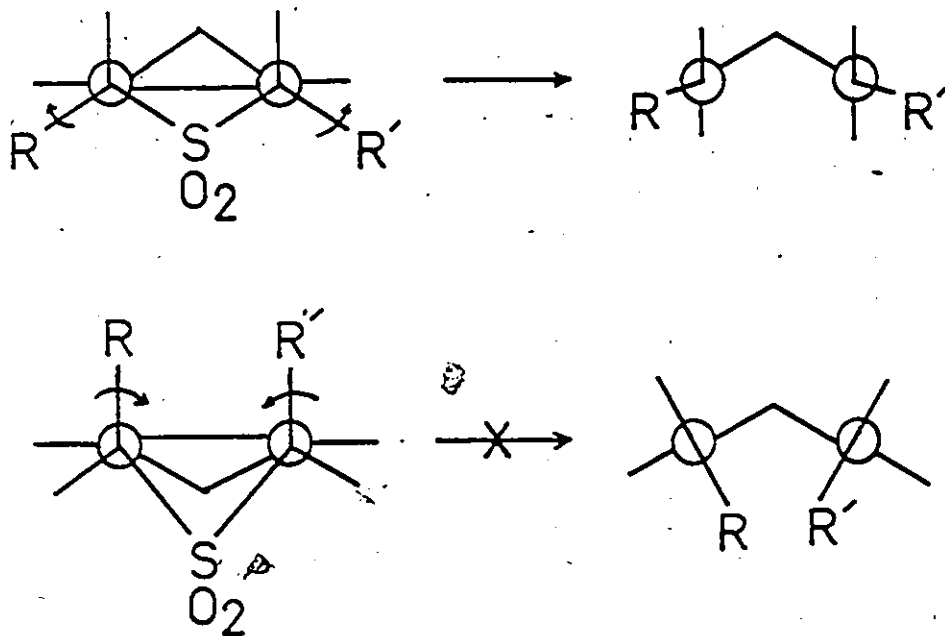


Figure 26. Fragmentation of the Bicyclic Sulfones to 1,4-Dienes

We have extended this model to explain the analysis of the products derived from the trans-2,5-dihydrothiophene sulfones. In Figure 27, the two disrotatory modes available for the elimination are outlined. In the second mode, rotation of the group at C-5 causes a serious eclipsing interaction with the substituent at C-4, a problem not encountered in the first mode. Thus our model suggests that we should isolate the (Z,E)- and not the (E,Z)-diene from the trans-2,5-dihydrothiophene sulfones. In both cases, our spectral data support these models.

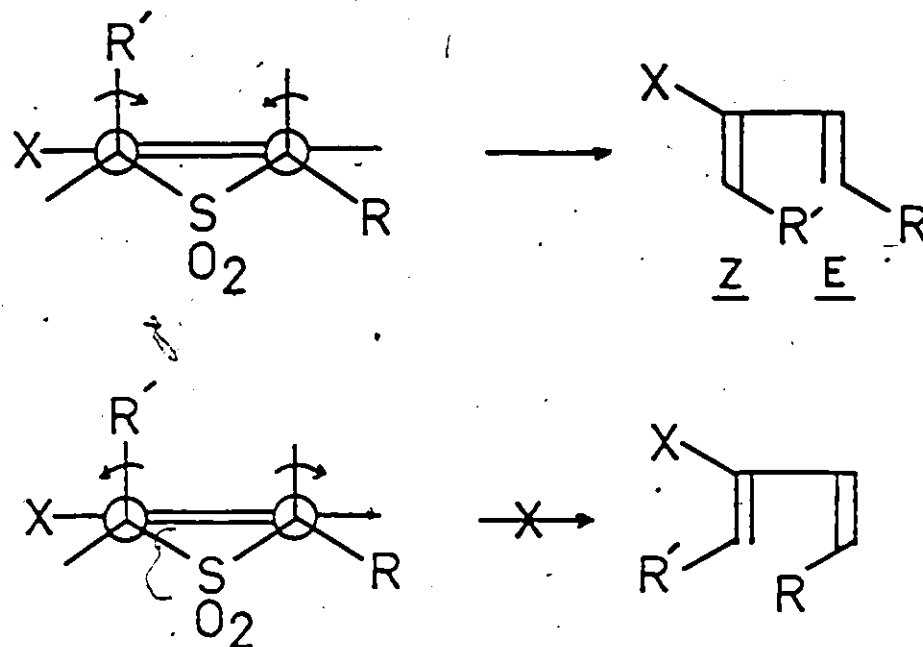


Figure 27. Pyrolysis of trans-Sulfones

It is evident from the foregoing that the formation of 2,5-dihydrothiophenes from vinylphosphonium salts is a stereoselective process, especially when the steric bulk of the substituents is not too large. Therefore, the overall synthesis allows for a regiospecific and stereoselective formation of conjugated dienes. The mildness of conditions, availability of starting materials and high yields make this method of potential importance in organic synthesis.

CHAPTER 3

SYNTHESIS AND REACTIONS OF ALKENYLSULFONIUM SALTSINTRODUCTION

In the first two chapters we have shown that the reaction of α -mercaptocarbonyl compounds and vinylphosphonium salts affords a stereoselective preparation of alkylated 2,5-dihydrothiophenes and how, in turn, these compounds can be transformed regiospecifically and stereoselectively into conjugated dienes. It is important to note that of the two oxidizable sites in the dihydrothiophenes, the sulfur atom is oxidized in preference to the carbon double bond using peracid. If it became desirable to epoxidize the double bond in the presence of sulfur, a new methodology would need to be developed. An obvious route to epoxides of this type would involve the use of vinylsulfonium salts. Therefore, we investigated the reaction of α -mercaptocarbonyl compounds and vinylsulfonium salts as a route to 3,4-epoxytetrahydrothiophenes 50 (Figure 28).

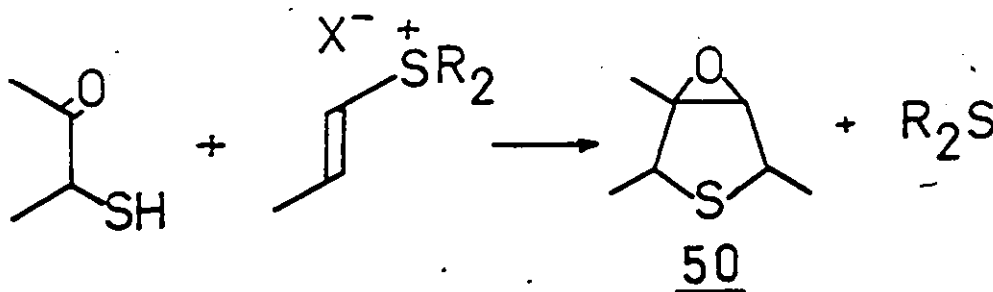


Figure 28. Proposed Preparation of Epoxytetrahydrothiophenes

The difference between the reactions involving vinylphosphonium salts and those involving vinylsulfonium salts can be seen from their respective mechanisms (Figure 29). In the case of vinylphosphonium salts, an initial Michael-type addition of the nucleophile generates an ylide which upon Wittig olefination affords the dihydrothiophenes. When vinylsulfonium salts are substituted in this reaction, we envisaged that the conjugate addition would occur to yield the sulfurane. Betaine formation should ensue and now the oxyanion so generated could displace dialkyl sulfide resulting in the oxirane. Delineation of the mechanistic aspects of product formation have been presented by Hatch⁷⁸. He found that in the case of "non-stabilized" sulfonium ylides, the formation of the betaine is irreversible. Thus, dissociation of the betaine into carbonyl and ylide partners does not complete with the elimination of the sulfide. This observation is emphasized in Figure 30. Thus, the mechanism of the reaction of aqueous benzyldimethylsulfonium chloride, formaldehyde, and sodium hydroxide involves (1) a rapid and reversible formation of dimethylsulfonium

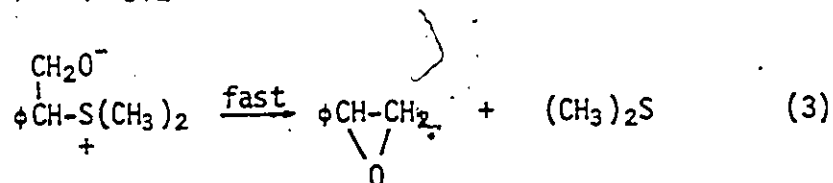
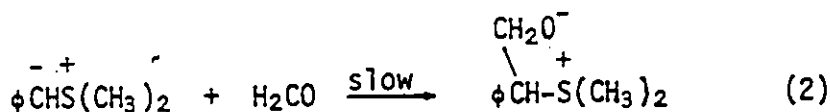
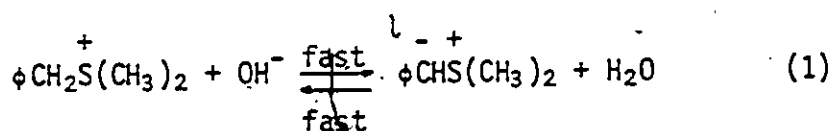


Figure 30. Reaction of Dimethylsulfonium Benzylide with Formaldehyde

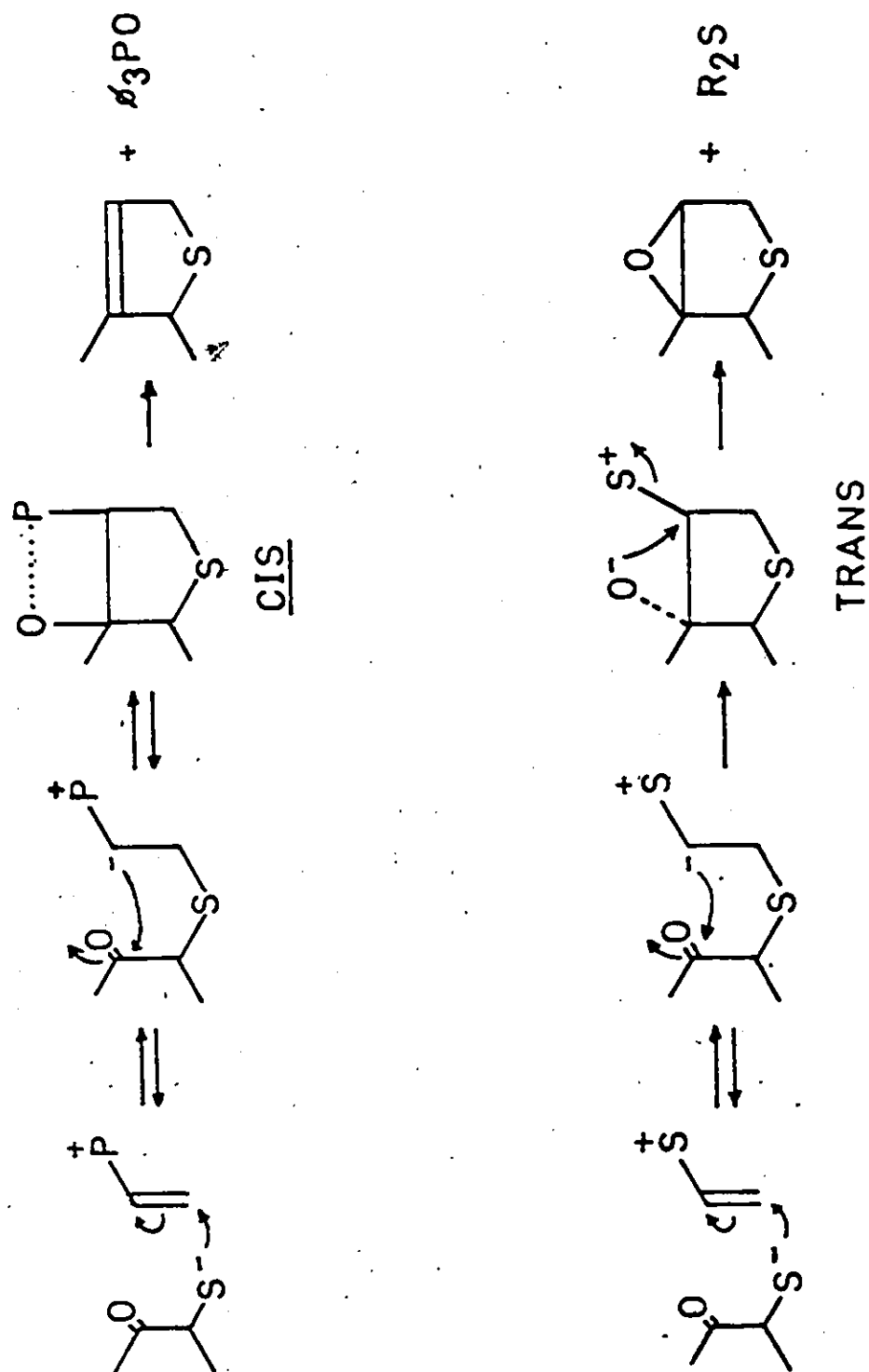


Figure 29. Reaction of α -Mercaptocarbonyl Compounds with Vinylphosphonium and Vinylsulfonium Salts

benzylide, (2) a rate-determining nucleophilic attack of the ylide on formaldehyde to form a betaine intermediate, (3) a rapid intramolecular displacement of dimethyl sulfide by the oxyanion to yield styrene oxide⁷⁸.

Another important comparison of the reactions of vinylphosphonium and vinylsulfonium salts involves the stereochemistry necessary for betaine decomposition. In the phosphorus case, since the betaine is formed reversibly, equilibration can occur to allow complete conversion to product. Betaine decomposition occurs when oxygen and phosphorus are cis to each other (oxaphosphetane ring). In the case of sulfonium salts, the nucleophilic oxyanion displaces the sulfide in an S_N2 manner⁶⁹. This intramolecular displacement can only proceed if the oxyanion is trans to the sulfur moiety being eliminated. In this case, however, since equilibration of the intermediate is not possible, if the initially formed betaine does not possess the required stereochemistry, ring closure to the epoxide is not possible. On steric grounds, one would assume that the proper stereochemistry for elimination 51 would be achieved. However, there is a moderately favorable electrostatic interaction which would favour the cis stereochemistry depicted in 52. If the betaine adopted this configuration it would be lost in the workup procedure as the β -hydroxysulfonium salt (Figure 31).

We assumed that the initial conjugate addition of the thiolate anion to the vinylsulfonium salt would be a viable course for the reaction to take. The ability of a sulfonium centre to provide "unusual" stabilization of an adjacent negative charge is well known⁸⁰. Noteworthy is the fact that dimethylvinylsulfonium bromide serves as a Michael acceptor whereas the corresponding ammonium salt does not^{81b}. One possible

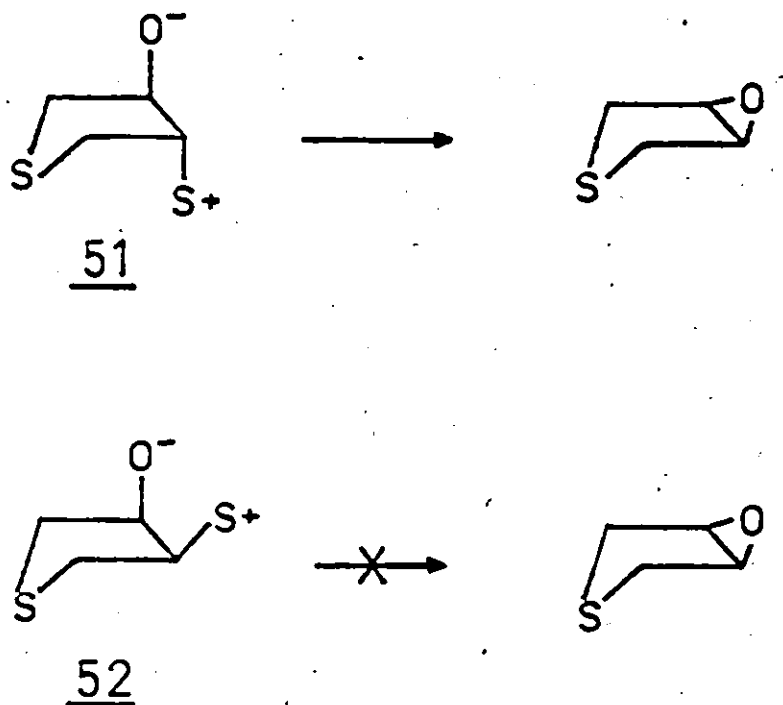


Figure 31. Stereochemistry of Betaine Decomposition
Leading to Epoxytetrahydrothiophenes

explanation of this phenomenon is that the 3d orbitals of sulfur can, in certain instances, overlap effectively with neighbouring 2p orbitals, and 3d - 2p π bonding of this type is held partly or wholly responsible for the stabilization of anionic centres adjacent to sulfur⁸¹. Caserio has found that this d-p π overlap in vinylsulfonium salts has little or no conformational requirement⁸². The stereochemical integrity found in some reactions involving sulfonium ylides may be explained by the "gauche effect"⁹².

Our attention was focused on compounds of type 50 for several reasons. First, our group has been interested in applying the reactions

(already described) to a biotin synthesis. It was evident from our previous work utilizing vinylphosphonium salts that we could construct a heterocyclic nucleus related to biotin with little effort. We felt that compounds like 50, where functionalization at the 3,4-positions of the dihydrothiophene had occurred with the versatile oxirane group, would be viable intermediates in a biotin synthesis (Figure 32). Since the completion of this work, Confalone has shown that 2,5-dihydrothiophene derivatives do form a basis for the total synthesis of biotin⁹³.

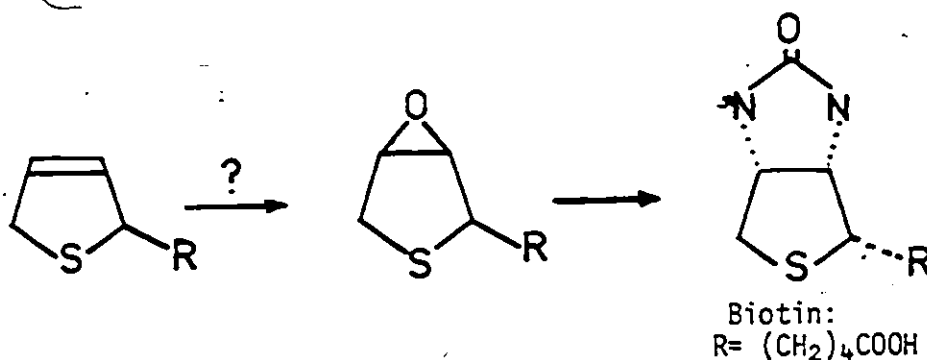


Figure 32. Epoxytetrahydrothiophenes as Biotin Intermediates

Secondly, we were anxious to investigate the possible role of these compounds in a stereospecific olefin synthesis: possibly as a route to insect pheromones. After extruding sulfur from the epoxytetrahydrothiophene, reductive elimination of the oxygen atom from the oxirane would afford a stereospecific (E) or (Z)-olefin depending upon the reagent employed^{94a,b}, (Figure 33).

It has been known for some time that vinylsulfonium salts are Michael acceptors. A variety of nucleophiles have been used as Michael

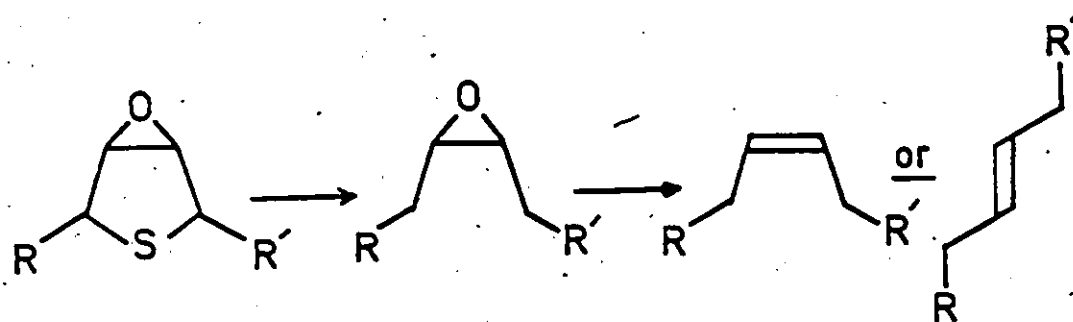


Figure 33. Epoxytetrahydrothiophenes as Olefin Precursors

donors. Included in this list are carbanions^{83a}, phosphoranes^{83b} and sulfuranes^{83c}. The reactions are shown in Figures 34, 35 and 36, respectively. A common event occurs in each of these reactions. Following the Michael addition to the double bond, anion transposition occurs and the loss of dimethyl sulfide leads to substituted cyclopropanes. It seems clear that whenever the occurrence of anion transposition results in the formation of a more stable carbanion, then this is the course the reaction is most likely to follow. Thus, in our case, if anion transposition occurred we would not expect an oxirane but a thiete 53 (Figure 37).

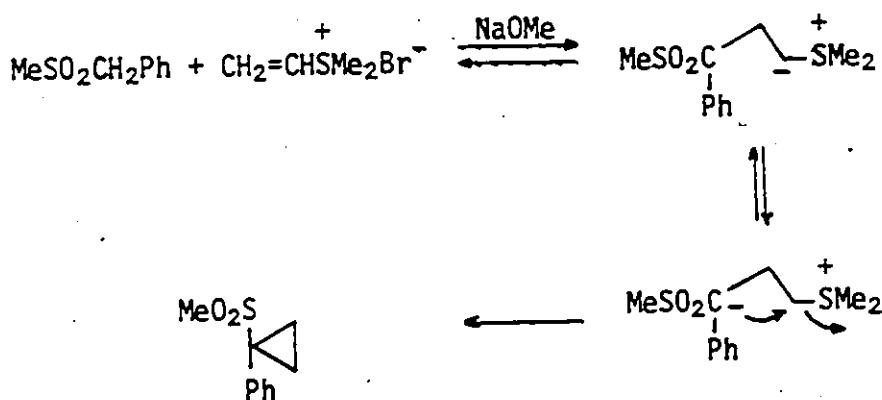


Figure 34. Reaction of Vinylsulfonium Salts and Carbanions

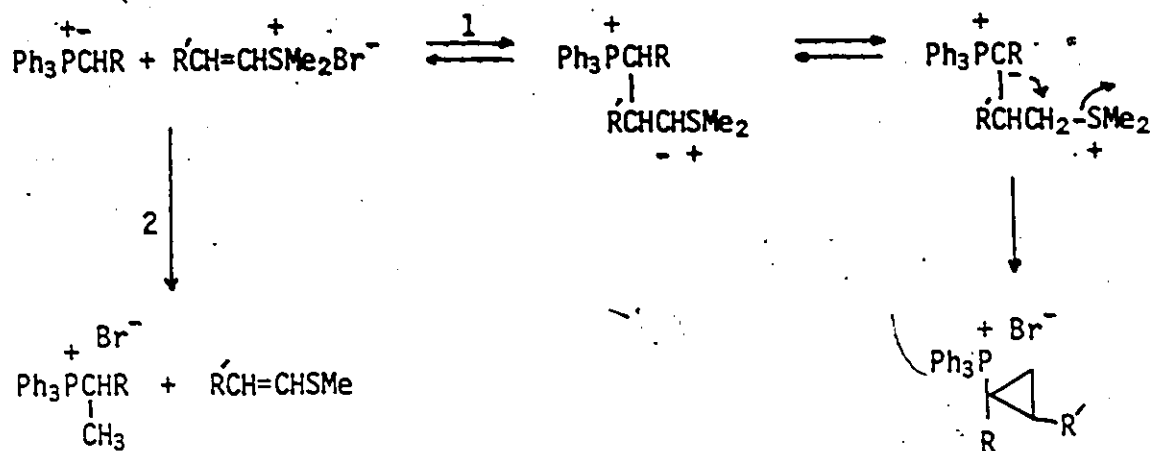


Figure 35. Reaction of Vinylsulfonium Salts and Phosphoranes

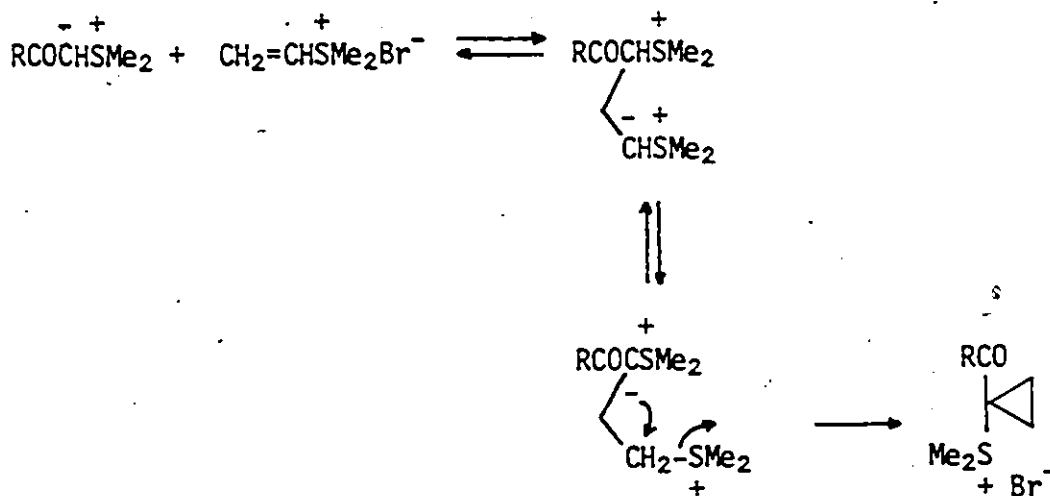


Figure 36. Reaction of Vinylsulfonium Salts and Sulfuranes

When a phosphorane is used as a nucleophile a serious side reaction competes with the conjugate addition (Figure 35). This is the nucleophilic demethylation of the sulfonium salt to yield a vinyl sulfide and the α -methylphosphonium salt. This type of reaction is well

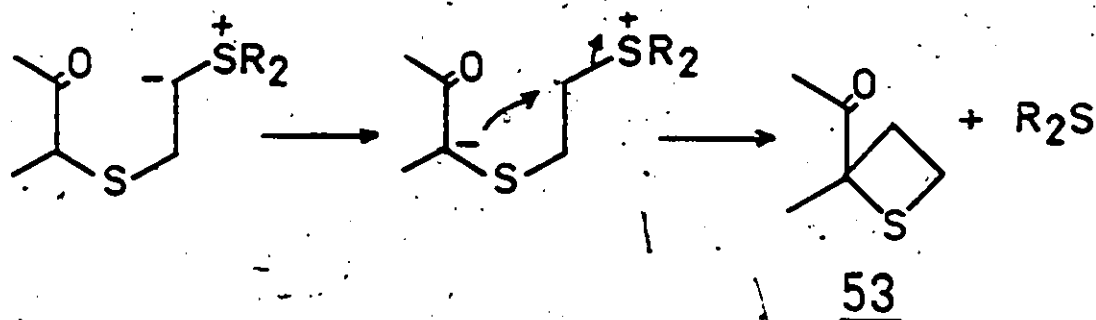
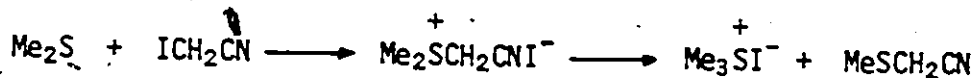


Figure 37. Thiete Formation Resulting from Anion Transposition

documented^{84,85}. One of the many examples is shown in Figure 38.



54

Figure 38. Nucleophilic Dealkylation of Sulfonium Salts

When Trost attempted to prepare cyanomethyldimethylsulfonium iodide 54 from iodoacetonitrile and dimethyl sulfide, he attained a 1:1 mixture of trimethylsulfonium iodide and methylthioacetonitrile⁸⁵. This reaction apparently proceeds through the expected salt 54 which is demethylated by the nucleophilic counterion. The methyl iodide produced in this manner reacts with dimethyl sulfide resulting in the products shown. Subsequent alkylation of methylthioacetonitrile can be effected quantitatively with a methylating agent possessing a non-nucleophilic counterion, e.g. trimethyloxonium tetrafluoroborate⁸⁵. This disproportionation reaction can be minimized by the use of excess alkylating agent and the addition of silver ion (to remove halide ion) is beneficial⁸⁶. These precautions are not always successful. In these instances, facilitation

of the disproportionation by heating followed by methylation of the formed sulfide is the preferable synthetic approach⁸⁷. Clearly, the use of nucleophilic counterions in the formation of methylsulfonium salts must be avoided.

As discussed earlier, the vinylphosphonium salts were prepared in situ by base-catalyzed isomerization of their allylic isomers. However, Trost reported that treatment of allyldiphenylsulfonium tetrafluoroborate with *n*-butyl lithium at -78° followed by quenching the ylide so formed with deuterioacetic acid led to greater than 90% yield of a monodeuterated sulfonium salt in which no detectable amount of the vinyl isomer was formed. Although it is conceivable that this reaction proceeded under kinetic control, it seemed unlikely to us that in situ isomerization of allylsulfonium salts would be successful in yielding their vinyl analogues. In a similar study, where the base-catalyzed olefin equilibria of a number of unsaturated sulfides, sulfoxides and sulfones were determined, it was found that the α,β -unsaturated sulfoxides and sulfones were much less stable than the β,γ -unsaturated isomers⁹⁵.

How then does one synthesize vinylsulfonium salts? A review of the literature offers four routes to these compounds (Figure 39). The first approach involves the alkylation of vinyl sulfides with powerful alkylating agents such as Meerwein's reagent⁸². Doering showed that weaker alkylating agents such as methyl iodide were not successful in the methylation of vinyl sulfides^{81b}, but he devised an alternate route to these compounds: alkylation of β -halo sulfides can be effected to give β -halosulfonium salts. Dehydrohalogenation of these compounds with silver oxide occurs in modest yield^{81b}. A third route to vinylsulfonium salts involves the reaction

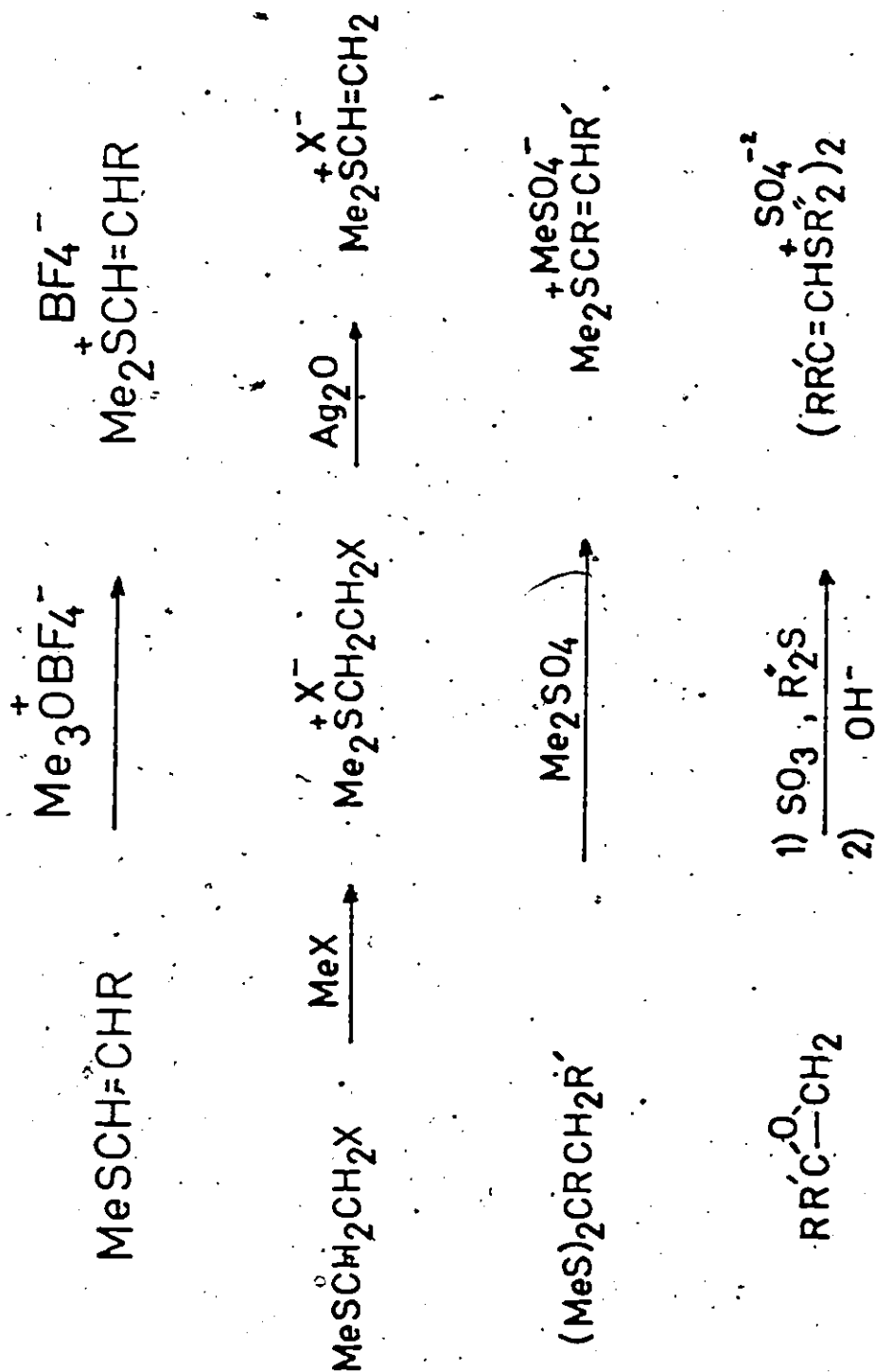


Figure 39. Synthesis of Vinyl Sulfonium Salts

of dithioketals with acid-free dimethyl sulfate⁸⁸. One drawback to this method is that it has only been successfully used for aryl-substituted compounds. A group of Japanese workers have shown that the reaction between 1,2-epoxyalkanes and the dimethyl sulfide-sulfur trioxide complex affords 1-dimethylsulfoniomethyl-1-alkyl sulfate which give vinylsulfonium salts upon treatment with alkali.⁸⁹

RESULTS AND DISCUSSION

We have found that a convenient method for the synthesis of vinylsulfonium salts of low molecular weight involves the reaction of vinyl sulfides and trimethyloxonium tetrafluoroborate in acetonitrile at -30° . The salts formed in this manner are hygroscopic and thermally unstable above 0° ^{82,86}. Thus, isolation of these compounds must be carried out in a dry box and they must be stored in a refrigerator. Routinely, we prepare and utilize these salts directly. Other methods used to prepare vinylsulfonium salts were not as effective. Dehydrohalogenation of β -halosulfonium salts with silver oxide could only be effected in modest yields. Modification of the method of Gosselck⁸⁸ (vide supra) to dithioacetals was not fruitful. The reaction of the dimethylthioacetal derived from butraldehyde with acid-free dimethyl sulfate at 90° for one hour led to the formation of a black tar from which no vinyl salt could be isolated. Repetition of this reaction under milder conditions (60° , 1 h) also proved unproductive.

The reaction between α -mercaptocarbonyl compounds and vinylsulfonium salts was carried out by first forming the vinylsulfonium salt in acetonitrile. In initial runs, the salts were isolated and the extent to which alkylation had occurred was determined. In subsequent experiments, ether was added to the reaction mixture since the formation of a precipitate upon ether addition served as a proof that alkylation of the sulfide had occurred. The addition of ether also allows the reaction mixture to withstand colder temperatures. The solution was cooled to -40° and a solution of the appropriate α -mercaptocarbonyl compound dissolved in

triethyl amine was added. The resulting golden solution was stirred at -40° for three hours and then allowed to reach ambient temperature. Isolation of pure materials was time consuming. Since preparative glc was found to be ineffective in purifying the products of a number of these reactions, especially when mercaptan 11 was used, preparative TLC (silica gel) using 5% ether in petroleum ether was employed.

To date we have spectral evidence to support the successful formation of four different oxiranes but in poor yield (Table 8). In no case can we find conclusive evidence for the formation of products related to thiete 53. In each case we retrieve a significant amount of methylated mercaptan. For reactions involving the salt 56, 1-butenyl methyl sulfide was also recovered. These products probably arise from demethylation of the sulfonium salt by the nucleophilic thiolate anion. This reaction would be irreversible and would help account for the low yields of epoxides obtained (Table 8). The low yields might also be accounted for, in part, by the rate of the oxirane forming reaction which will be lowered if the proper stereochemistry for elimination is not attained. We have not attempted to isolate any of the β -hydroxysulfonium salt derived from 52.

Since the major product isolated from our workup procedure is the methylated mercaptan, the syntheses of salts which would not be susceptible to dealkylation were investigated. We attempted the isomerization of allyldiphenylsulfonium tetrafluoroborate under what we assumed were thermodynamically controlled conditions. Refluxing the allylic salt in the presence of triethyl amine afforded only the allylic salt and no detectable amount of the vinyl isomer was observable in the nmr spectrum.

TABLE 8 - Formation of 3,4-Epoxytetrahydrothiophenes^a

<u>Mercaptan</u>	<u>Salt</u>	<u>Product</u>	<u>R₁</u>	<u>R₂</u>	<u>R₃</u>	<u>R₄</u>	<u>% yield^b</u>
<u>11</u>	<u>55</u>	<u>57</u>	-(CH ₂) ₄		H	H	20
<u>10</u>	<u>56</u>	<u>58</u>	Me	Me	Me	Et	25
<u>14</u>	<u>56</u>	<u>59</u>	H	Et	H	Et	20
<u>16</u>	<u>56</u>	<u>60</u>	Et	Me	H	Et	20

a) see Figure

b) significant amount of methylated mercaptan isolated in each case.

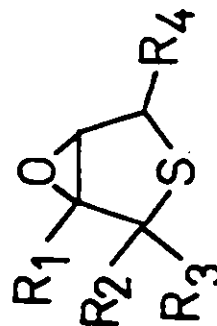


TABLE 9 - Nmr Spectra of 3,4-Epoxytetrahydrothiophenes

<u>Compound</u>	<u>Nmr Spectral Data^a</u>
<u>57</u>	3.8-3.25 (m,3), 3.0-1.3 (m,9).
<u>58</u>	3.7-3.3 (m,2); 2.4-2.15 (m,3), 1.5-1.15 (m,2), 1.4 (s,3), 1.35 (s,3), 0.98 (t,3,J=8).
<u>59</u>	4.2-3.9 (m,1), 3.7-3.2 (m,1), 2.5-2.0 (m,2), 2.0-0.7 (m,10).
<u>60</u>	4.0-3.25 (m,2), 2.9-2.4 (m,3), 2.4-1.7 (m,2), 1.35 (d,3,J=7), 1.1 (2t,6,J=7.5).

a) Deuteriochloroform was employed as solvent using TMS as internal standard.

Based on the assumption that a small equilibrium amount of the vinyl salt might be present, we refluxed the allylic salt 61 with pyridine/triethyl amine for one hour and then added 11. The product isolated in good yield was 62 (Figure 40). This product results from the nucleophilic displacement of tetrahydrothiophene from the allyl salt and is simply another example of the dealkylation reaction.

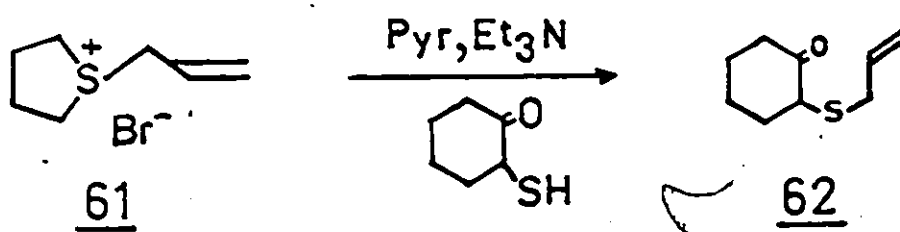


Figure 40. Reaction of the Allylsulfonium Salt with Mercaptan 11

Because of the low yields involved in this reaction it is unlikely that we will be utilizing these oxiranes to any great extent and unless the yields can be improved, the synthetic utility of these compounds appears to be minimal. Thus, this route was abandoned.

There is precedence in the literature to support the observation that the thiolate anion is a better nucleophile than Michael donor. These results are summarized in Figure 41. When Braun⁹⁰ reacted the oxyanion from an alkoxide with butadienyldimethylsulfonium bromide 63, he obtained a conjugate addition of the alkoxide and was able to quench the ylide so formed with an aldehyde to yield 64. Anomalous results were obtained when thiophenoxide was substituted as the Michael donor. The product isolated was not the sulfur equivalent of 64 but 1,4-diphenylthio-2-butene 65.

We also became interested in the sulfonium salt 63. Recently, our group utilized the butadienylphosphonium salt in the Michael-Wittig

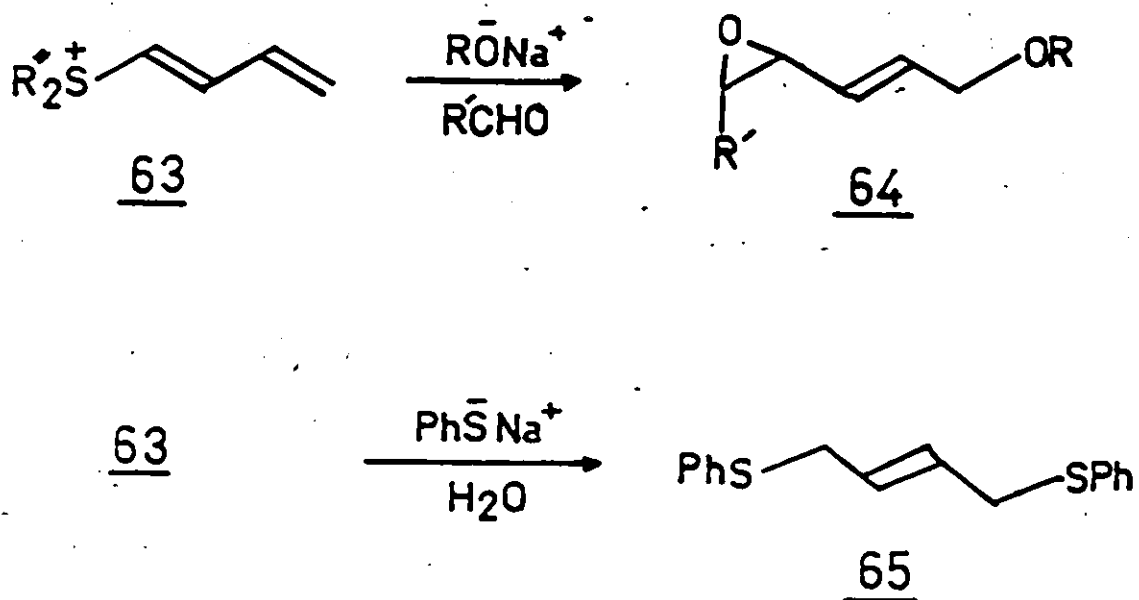


Figure 41. Reaction of the Butadienylsulfonium Salt with Nucleophiles

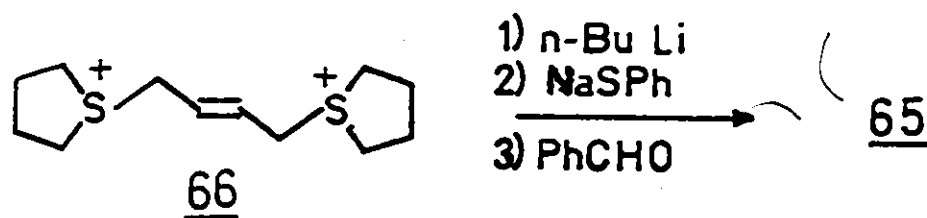


Figure 42. Butadienylsulfonium Salts with Sodium Thiophenoxide

sequence outlined in Chapter 1⁵⁷. The results we obtained were unexpected and in order to further extend this work, we felt a study of this reaction with the butadienylsulfonium salt was necessary. Thus, we repeated the reaction of 63 with thiophenoxide under a variety of anhydrous conditions and in the absence of any protolytic solvents only to find that 65 was the only isolable organic product. The use of salt 66 leads to identical results.

An alternative mechanism is possible when 66 is utilized (Figure 42). Whereas reactions with 63 were carried out on isolated material, reactions with 66 were performed under conditions where the butadienylsulfonium salt was formed in situ. However, isolation of the butadienyl salt derived from 66 could not be achieved and therefore the formation of 65 from salt 66 probably occurs by the direct displacement of two equivalents of tetrahydrothiophene from the salt by the thiophenoxide anion.

CHAPTER 4

β -BROMOSULFONIUM SALTS

INTRODUCTION

In an attempt to improve the synthesis of the tetrahydrothiophene epoxides, we turned our attention to the use of a synthon for the vinyl salt. The use of β -bromosulfonium salts offered the possibility of achieving a nucleophilic displacement of bromide by the thiolate anion. It has been documented by Streitwieser⁹⁶ (Table 10) that bromide is a better leaving group than dimethyl sulfide and by taking advantage of this fact, the nucleophilic displacement of bromide by the thiolate anion of α -mercapto-carbonyl compounds should be a viable approach to compounds related to 67 (Figure 43). When the resulting sulfonium salts are treated with a base, we

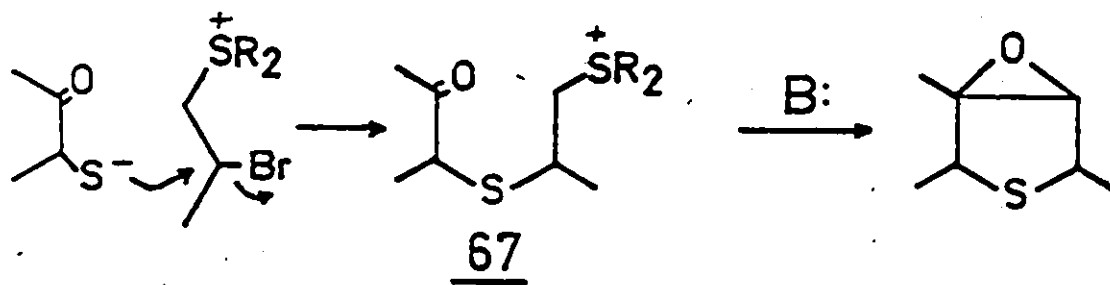


Figure 43. Reaction of β -Bromosulfonium Salts with Thiolate Anions

TABLE 10

Relative Leaving Group Ability^a

<u>Leaving Group</u>	<u>Relative Rate</u>
N ₂	High
OSOCl	High
OCIO ₃	~2000
OSO ₂ C ₆ H ₅	6
I	3
Br	1
OH ₂ ⁺	1 ^b
S(CH ₃) ₂ ⁺	0.5 ^b
Cl	0.02
CNO ₂	0.01
F	0.0001

a) In displacement reactions relative to bromide ion.

b) In ethanol.

hoped that formation of the sulfur ylide would lead to the desired 3,4-epoxytetrahydrothiophenes, although another possibility was the elimination of the mercaptide resulting in the formation of vinyl salts.

The role of the group which is displaced (the "leaving group") in an S_N2 reaction is not well defined. The leaving group must be capable of accepting a pair of electrons, often as a negative charge. A relationship should be found between the acidity of the compound from which the leaving group is derived and the facility with which that group departs from the substrate in a nucleophilic displacement reaction. The leaving group abilities found in Table 10 are based on averaging results from a number of displacement reactions⁹⁷.

The literature presents two methods for the synthesis of β -halosulfonium salts. The first has been discussed in Chapter 3. Doering^{81b} has shown that treating β -halo sulfides with alkylating agents such as methyl bromide or ethyl iodide for 5 days at 0° allows the successful transformation of these compounds into β -halosulfonium salts (Figure 44).

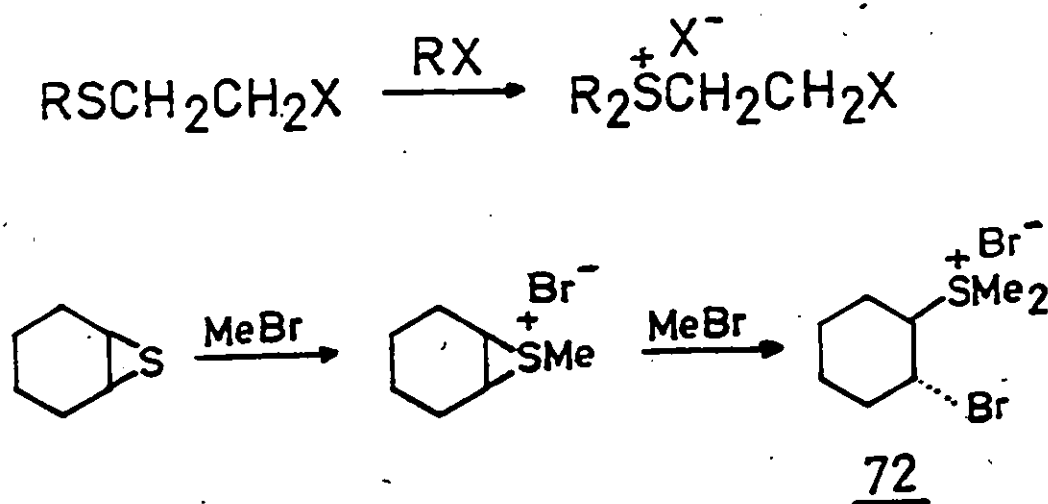


Figure 44. Synthesis of β -Halosulfonium Salts

Subsequent treatment with silver oxide effects dehydrohalogenation and affords a route to the vinylsulfonium salts (Figure 39). One drawback to this method is the undesirable use of β -halo sulfides which are sulfur "mustards" and must be handled with extreme care. The second method available to synthesize β -halosulfonium salts involves the double alkylation of episulfides. Thus, cyclohexene sulfide and excess methyl bromide in acetonitrile (Figure 44) produced trans-1-bromo-2-dimethylsulfoniocyclohexane bromide 72 in 41% yield after 4 days¹¹³. However, episulfides are not easily prepared in good yield. Another drawback to both the above methods is the long reaction time required. In addition, the synthesis of β -haloalkyldi-phenylsulfonium salts would not be feasible by either of the routes outlined. The most serious obstacle to the epoxytetrahydrothiophenes as outlined in Chapter 3 was the side reaction leading to vinyl sulfides. We felt that the use of diphenylvinyl salts might preclude this problem. However, there is no procedure available at the present time for the synthesis of diphenylvinylsulfonium salts.

Our strategy for the synthesis of β -bromosulfonium salts involves a simple concept: viz., entrapping a bromonium ion with a nucleophilic species such as a sulfide (Figure 45). The use of diphenyl sulfide in

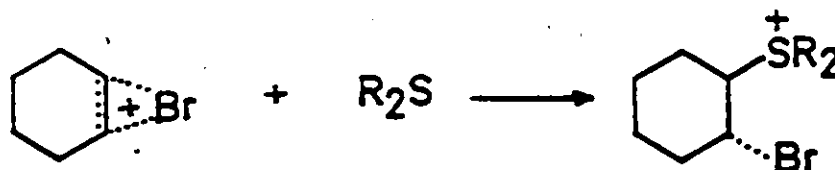


Figure 45. Proposed Route to β -Bromosulfonium Salts

this reaction might be considered a possible route to the diphenylvinyl-sulfonium salts although we felt that the well-known low nucleophilicity of diphenyl sulfide might reduce the yields obtained by this route.

The reaction of bromine with an olefin is thought to proceed by electrophilic attack of the halogen on the double bond to form an intermediate bromonium ion 68 (Figure 46)⁹⁸. Under special circumstances,

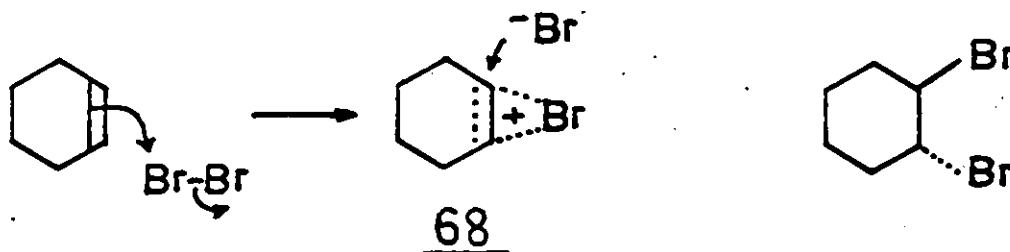


Figure 46. Addition of Bromine to Cyclohexene

stable solutions of bromonium ions have been obtained for nmr studies⁹⁹. In the usual reaction sequence, the bromonium ion is attacked by the bromide ion and the overall result is the trans addition of the two halogen atoms to the double bond. The bromonium ion is produced by attack of the halogen from the least hindered side of the double bond. This stereochemical result is illustrated by the bromination of cholesterol¹⁰⁰ and 2-cholestene¹⁰¹.

As might be anticipated from the above discussion, the bromonium ion can react with any nucleophile in the reaction medium¹⁰². For example, trans-stilbene reacts with bromine in methanol to give a mixture of dibromide and methoxybromide¹⁰³ (Figure 47). Other nucleophiles that have been employed in this reaction include: acetic acid¹⁰⁴ and water¹⁰⁵. These examples illustrate the fact that the nucleophile will attack the carbon

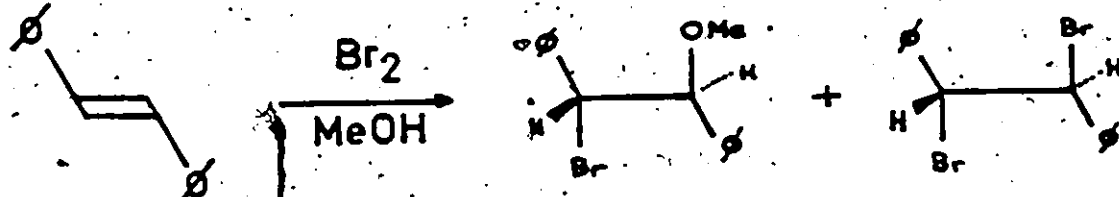


Figure 47. Reaction of Bromine in Methanol with trans-Stilbene

atom which is better able to stabilize a positive charge.

A more synthetically useful procedure might be the use of a source of positive bromine in these reactions. N-bromoamides (such as N-bromosuccinimide¹⁰⁶ or N-bromoacetamide¹⁰⁷) have been used successfully as has bromine azide¹⁰⁸. It is often advantageous to use a cosolvent¹⁰⁹ such as dimethyl sulfoxide or dimethylformamide but caution must be exercised since solvents such as dimethyl sulfoxide, dimethylformamide, acetonitrile and acetone may also be used as nucleophiles which attack bromonium ions¹⁰⁸.

The mechanism of this reaction is exemplified in the case of an N-bromoamide¹⁰⁶ (Figure 48). Electrophilic attack of the olefin by the protonated N-bromoamide results in the formation of a bromonium ion. Attack of the nucleophile on the incipient three-membered ring bromonium ion and subsequent loss of a proton leads to the product.

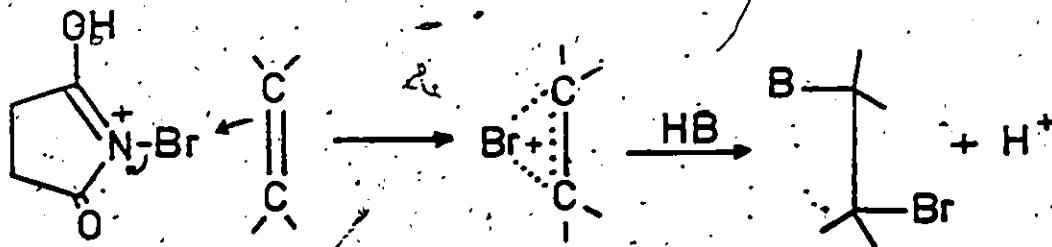
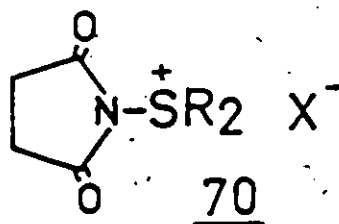
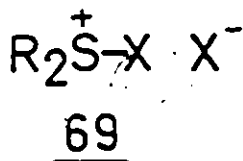
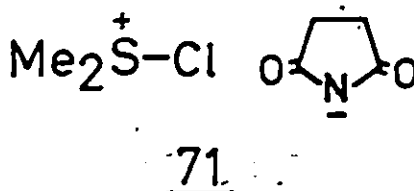


Figure 48. NBS as a Source of "Positive Bromine"

The well-known complexes which result from reactions of halogens or N-haloamides and sulfides^{110,111} (69,70), have been used by Corey¹¹¹ for the oxidation of primary and secondary alcohols to carbonyl compounds.



The question of tetravalent or sulfonium sulfur in these complexes merits further study. The structure of 70 is very interesting. Assuming that N-halosuccinimides are sources of positive halogen, then one might expect the complex between N-chlorosuccinimide and dimethyl sulfide would be the S-chlorosulfonium salt 71. This structural problem was examined by Vilsmaier¹¹² and he found that 70 and not 71 was the product



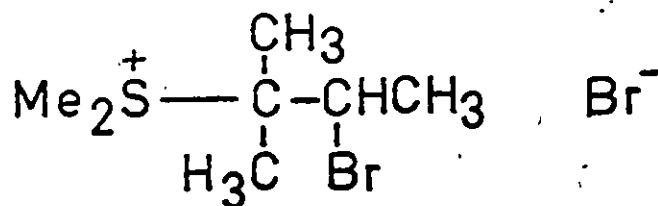
of the reaction. The infrared spectrum of the isolated product proved to be definitive.

It was our intention to react species such as 69 and 71 with olefins as a route to β -halosulfonium salts.

RESULTS AND DISCUSSION

We have investigated the reaction of olefins with a mixture of halogens and sulfides as a route to β -halosulfonium salts. When bromine is added dropwise to a large excess of dimethyl sulfide, a yellow solid develops immediately which we identify as the sulfonium salt 69 ($R = \text{Me}$, $X = \text{Br}$). Addition of an olefin to the reaction mixture leads to the isolation of β -bromosulfonium salts in fair yields (Table 11, 12). We propose that the mechanism for this reaction is analogous to the reaction of carbon-carbon double bonds with N-bromosuccinimide, where, in our case, the incipient bromonium ion is attacked by the large excess of dimethyl sulfide, which is used as the solvent for the reaction. Although two nucleophilic species are present in the reaction mixture (bromide and dimethyl sulfide), when the reaction is carried out in dimethyl sulfide as the solvent, the concentration factor greatly outweighs the nucleophilicity and the sulfonium salt is produced.

In the two cases, 74 and 75, where unsymmetrical olefins were utilized, the major salt isolated was the product of Markownikov addition of bromodimethylsulfonium bromide. The product isolated from 2-methyl-2-butene was 75 with no detectable amount of the other isomer. When 2-octene was employed, there was a 3:2 ratio (nmr) of products formed



75

TABLE 11

 β -Bromosulfonium Salts

<u>olefin</u>	<u>Salt</u>	<u>yield (%)</u>	<u>mp</u>
cyclohexene	<u>72</u>	53	143-144 ^{0a}
cyclopentene	<u>73</u>	34	133-135 ^{0d}
2-octene	<u>74a</u> , <u>74b</u>	21	72-75 ^{0b}
2-methyl-2-butene	<u>75</u>	29	135-137 ⁰
2-butene	<u>76</u>	20	c

a) lit.¹⁰⁰ mp 145-147⁰.

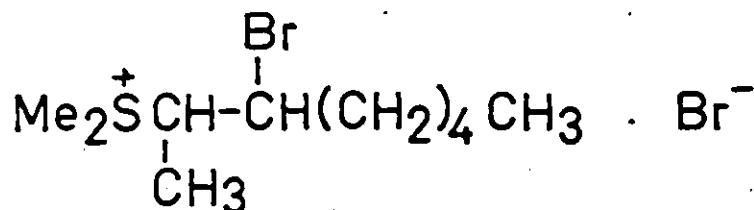
b) mixture of isomers.

c) trimethylsulfonium bromide ~~present~~ as impurity.

TABLE 12 - Nmr Spectra of the β -Bromosulfonium Salts

<u>Compound</u>	<u>Nmr Spectra Data^a</u>
<u>72</u>	4.4-3.5 (m,2), 2.95 (d,6,J=9), 2.7-1.2 (m,8).
<u>73</u>	4.55-3.7 (m,2), 3.05 (d,6,J=8), 2.8-1.55 (m,6).
<u>74a</u>	4.5-3.7 (m,2), 3.00 (d,6,J=2), 1.72 (d,3,J=7), 1.6-0.7 (m,11).
<u>74b</u>	4.5-3.7 (m,2), 3.0 (d,6,J=2), 1.97 (d,3,J=7), 1.6-0.7 (m,11).
<u>75</u>	4.37 (q,1,J=7), 2.9 (d,6,J=2), 1.86 (d,3,J=7), 1.68 (s,6).
<u>76</u>	4.7-3.7 (m,2), 2.95 (s,6), 1.77 (d,3,J=7), 1.6 (d,3,J=7).

a) Trifluoroacetic acid employed as solvent with TSP as internal standard.

74a

where the major isomer was 74a in which dimethyl sulfide had attacked the bromonium ion at the end bearing the smaller substituent.

We have had no success in isolating the β -bromosulfonium salt when terminal olefins such as 1-hexene or 1-octene were used. Also, no β -bromosulfonium salt could be isolated when tetrahydrothiophene or diphenyl sulfide was substituted as the reaction solvent.

Although the yields are moderate to poor, the availability of starting materials, ease of reaction and cost of the necessary materials make this an attractive method for the synthesis of β -bromosulfonium salts derived from symmetrical olefins.

The negative results obtained when diphenyl sulfide was employed as the solvent were extremely disappointing. One of the chief disadvantages we are faced with in the conjugate addition-cyclization sequence with vinylsulfonium salts is the nucleophilic dealkylation of the vinyl salts to vinyl sulfides. The use of diphenylvinylsulfonium salts would have circumvented this problem, but these salts are still not obtainable by any known method.

Adapting a procedure developed by Doering^{81b}, we have shown that the β -bromosulfonium salt 72 can be dehydrohalogenated with silver oxide to the vinyl salt. Therefore, our procedure allows for the synthesis of a number of α -substituted vinylsulfonium salts.

We felt that the poor yields of β -bromosulfonium salts obtained from some reactions were due, in part, to the formation of the dibromide; that is, where bromide had reacted as the nucleophile instead of dimethyl sulfide. Thus, we investigated the use of N-bromosuccinimide as a source of positive bromine where the counterion was non-nucleophilic. However, the product isolated from the reaction of NBS, dimethyl sulfide and an olefin was 70 (R= Me, X= Br) which supports the work of Vilsmaier¹¹². None of the salt derived from 71 (X= Br) was obtained.

At the risk of ending this dissertation on a negative note, I must report that the reaction of α -mercaptocarbonyl compounds with β -bromosulfonium salts is not successful in yielding the epoxytetrahydrothiophenes. When salt 73 is reacted with α -mercaptoketone 10 in ethanol for four hours at -78° and the resulting solution is treated with one equivalent of potassium tert-butoxide, the major product isolated from the reaction mixture was the methylated mercaptan (Figure 49), yet another example of the nucleophilic dealkylation of sulfonium salts.

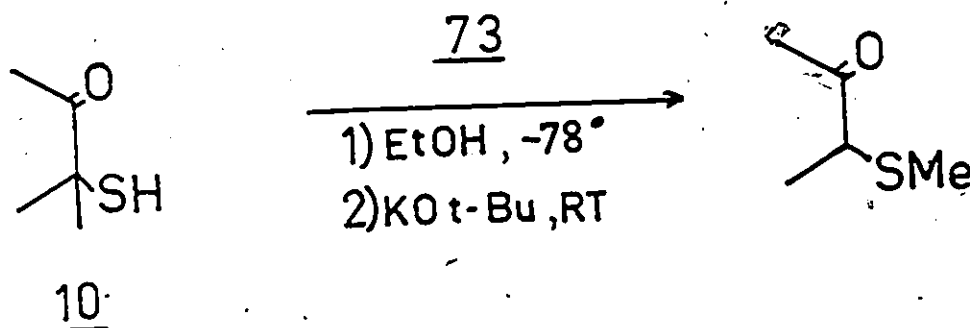


Figure 49. Reaction of Mercaptan 10 with β -Bromo Salt 73

Clearly, if the type of reaction developed in Chapter 1 is going to have any application in sulfonium salt chemistry, the synthesis of vinylsulfonium salts not susceptible to dealkylation must be accomplished. A general route to diphenylvinylsulfonium salts is a synthetic problem worth investigating.

CONCLUSION

2,5-Dihydrothiophenes can be formed in excellent yield by the reaction of α -mercaptocarbonyl compounds and vinylphosphonium salts. Oxidation of the dihydrothiophenes results in the quantitative formation of the corresponding sulfones. Thermolysis of these compounds affords a general synthesis of conjugated dienes, regiospecifically and stereoselectively.

When vinylsulfonium salts are substituted in the reaction, the expected 3,4-epoxytetrahydrothiophenes are not the major products. Dealkylation of the vinylsulfonium salts supercedes the desired reaction and results in the formation of vinyl sulfides and the corresponding methylated mercaptans.

β -Bromosulfonium salts can be synthesized in moderate yields by the reaction of bromodimethylsulfonium bromide with olefins. Dehydrohalogenation of these compounds to vinylsulfonium salts can be effected with silver oxide. The use of diphenyl sulfide in this reaction is not successful in yielding the β -bromoalkyldiphenylsulfonium salts.

CHAPTER 5

EXPERIMENTAL

GENERAL INFORMATION

Unless otherwise stated, nuclear magnetic resonance (nmr) were obtained on a Jeolco C60HL spectrometer or a Varian EM-360 spectrometer and are reported in parts per million downfield (δ) from TMS as an internal standard. The following code was utilized: nmr (solvent) δ (multiplicity, number of protons, coupling constant).

Compounds characterized by infrared spectrometry were recorded on a Beckman IR-12 or Beckman IR-20A spectrometer and are reported in wave numbers (cm^{-1}) in the solvent indicated.

Glc analysis was carried out on a F&M model 720 and Hewlett-Packard 5750 gas chromatographs using a helium carrier gas at a flow rate of 1 cc sec⁻¹. Injection port temperature and detector temperature were 310°C and 325°C respectively. The following columns were used: A) 8' x 0.375" o.d. 20% SE-30 on Chromosorb W (NAW); B) 10' x 0.375" o.d. 20% tris-(2-cyanoethoxy)-propane (TCEP) on Chromosorb P (NAW); C) 10' x 0.375" o.d. SE-30 on Chromosorb W (NAW); D) 10' x 0.125" o.d. SE-30 on Chromosorb W (NAW). Composition of mixtures were determined using a disc integrator and are considered accurate to $\pm 3\%$. Mass spectra were obtained on a Varian MAT CH5-DF instrument.

Unless otherwise noted, the drying agent used was anhydrous sodium sulfate and solvents were removed in vacuo. Column chromatography

was performed on Fisher acidic alumina (80-100 mesh) Brockman activity grade I. Melting points were preformed on a Fisher-Johns apparatus and are uncorrected. Yields reported may not be optimum and describe isolated material. Microanalysis were preformed by A. B. Gygli, Microanalysis Laboratory, Toronto, Ontario.

PREPARATION OF VINYLPHOSPHONIUM SALTS

Vinyltriphenylphosphonium bromide ⁷⁴ 18 was purchased from the Aldrich Chemical Company.

2-METHYLVINYLTRIPHENYLPHOSPHONIUM BROMIDE ⁴² 19

A solution of 5 g of allyltriphenylphosphonium bromide 19a in 40 ml of dry pyridine containing 6 drops of triethyl amine was stirred at room temperature for 18 h. After removal of solvent, purification was effected by adding 50 ml of boiling benzene followed by enough methylene chloride to effect solution, cooling to room temperature and precipitating the salt with 20 ml of ethyl acetate. The yield was 96%, mp 210-212° (lit. ⁴² mp 213-214°), nmr (CDCl₃) δ7.85-7.3 (m,20), 7.25-6.2 (m,2), 2.45-2.2 (m,3).

2,2-DIMETHYLVINYLTRIPHENYLPHOSPHONIUM CHLORIDE 20

Equimolar amounts of triphenylphosphine and methallyl chloride were refluxed in benzene overnight. The solvent was removed and the residue was recrystallized in the same manner as for 19: mp 211-213° (lit. ^{49a} mp 214-216° reported as 20a); nmr (CDCl₃) δ7.80-7.38 (m,15), 6.48 (d,1,J=20), 2.42 (br s,3), 1.76 (d,3,J=2). An alternate procedure whereby a large excess of methallyl chloride was used as the reaction solvent afforded a

crude product whose nmr spectrum showed it to be a 5:1 mixture of salts 20a and 20.

α -BROMOMETHYLSTYRENE

α -Methylstyrene (94.4 g, 0.8 mol) and 90 g (0.5 mol) of N-bromosuccinimide were mixed under a nitrogen atmosphere in a 1000 ml r.b. flask fitted with a magnetic stirrer, a reflux condenser, and a addition funnel containing 400 ml carbon tetrachloride. The stirrer was started and the flask was heated with a Meker burner until the solid started to melt. An exothermic reaction started and the flask was cooled in an ice bath to moderate the reaction. After the reaction had subsided, the mixture was stirred for 2 h, the carbon tetrachloride was added, and the insoluble material was removed by filtration. The residue was washed with solvent and the filtrate was evaporated to afford 95 g of a dark oily lachrymator¹¹⁴ which was used without further purification.

nmr (CCl₄) δ 7.65-7.1 (m,5), 5.5 (s,1), 5.43 (br s,1), 4.35 (s,2).

2-PHENYL-1-PROPEN-3-YLTRIPHENYLPHOSPHONIUM BROMIDE 23a.

Crude α -bromomethylstyrene (80 g, 0.4 mol) was dissolved in 50 ml of methylene chloride and 107 g (0.41 mol) of triphenylphosphine was added. The solution was heated at reflux for 24 h. The cooled solution was filtered and the filtrate was diluted with 50 ml ethyl acetate and refiltered. The combined residues were washed with ethyl acetate and dried to yield 59 g of salt 23a: mp 224-226°; nmr (CDCl₃) δ 8.0-6.8 (m,20), 5.5-5.1 (m,4).

Anal. Calcd. for C₂₇H₂₄PBr: C, 70.57; H, 5.27; P, 6.75. Found: C, 70.71; H, 5.40; P, 6.70.

2-PHENYL-2-METHYLVINYLTRIPHENYLPHOSPHONIUM BROMIDE 23

Salt 23a (60 mg) was dissolved in pyridine- d_5 in a nmr tube and 2 drops of triethylamine was added. After 30 min, the absorption at δ 5-6 has completely disappeared. Repeating the procedure on a preparative scale led to the isolation of salt 23a and an oil which could not be crystallized, but whose nmr spectrum was consistent with structure 23; nmr ($CDCl_3$) δ 7.9-7.35 (m, 20), 7.1-6.3 (m, 1), 2.20 (d, 3, $J=3.5$). This salt was normally prepared in situ from 23a.

3-METHYL-2-BUTEN-1-YLTRIPHENYLPHOSPHONIUM BROMIDE 22a

To a solution of 7.0 g (0.02 mol) of triphenylphosphine hydrobromide ¹¹⁵ in 50 ml of acetonitrile was added 3.0 g of isoprene, and the solution was stirred for 15 h. The salt was precipitated by adding 150 ml of ethyl acetate, filtered and dried to give 8.2 g (100%) of a solid: mp 230-234° (lit. ¹¹⁶ mp 233-235°); nmr ($CDCl_3$) δ 8.0 (m, 15), 5.5-4.5 (m, 3), 1.75 (d, 3, $J=7$), 1.35 (d, 3, $J=4.5$).

Refluxing a solution of this salt in pyridine containing some triethylamine for 3 h caused its isomerization into salt 22.

Mercapto~~carbonyl~~ compounds 14^{54} , 15^{117} and 11^{53a} were prepared by literature methods.

2-BROMO-3-PENTANONE

To a mechanically stirred slurry of 110 g (1.1 mol) of calcium carbonate and 87 g (1 mol) of 3-pentanone in 1 l of cold chloroform was added dropwise 145 g (0.9 mol) of bromine over a period of 4 h at 0°.

After addition was complete, the mixture was stirred for 3 h, filtered and the filtrate was washed with 300 ml of saturated aqueous sodium bicarbonate solution and dried (MgSO_4). Removal of the solvent gave an oil which was distilled to give the bromoketone (80 g, 55%), bp 55° (15 mm) [lit.¹¹⁸ bp 48° (12 mm)].

2-MERCAPTO-3-PENTANONE

A solution of 30 g of potassium hydroxide in 150 ml of water was saturated with hydrogen sulfide at 0° . With continuous addition of hydrogen sulfide, 45 g (0.27 mol) of 2-bromo-3-pentanone in 10 ml of absolute ethanol was added dropwise with stirring over a period of 2 h. The solution was stirred for 2 h as it warmed to room temperature and then extracted with two 75 ml portions of ether. The ether extracts were washed with water, dried and evaporated to give 25 g (78%) of pure mercaptan which was used without distillation: nmr (CCl_4) δ 3.45 (d of q, 1, $J=9.5, 7.5$), 2.9-2.4 (d of q, 2, $J=2, 7$), 1.8 (d, 1, $J=9.5$), 1.4 (d, 3, $J=7.5$), 1.1 (t, 3, $J=7$).

2-MERCAPTOPROPIONALDEHYDE

To a cold mixture of 56 g of finely pulverized sodium sulfhydrylate in 250 ml of ether was added 25 g (0.18 mol) of 2-bromopropanal¹¹⁹, bp $42-50^\circ$ (60 mm). The slurry was stirred vigorously overnight and filtered. The solvent was removed to afford an oil which solidified on trituration with methanol: yield 1.0 g (6%); nmr ($\text{DMSO}-d_6$) δ 5.93 (d, 2, $J=6$), 4.7 (br d, 2, $J=6$), 3.63 (br q, 2, $J=7.5$), 1.06 (d, 6, $J=7.5$). The material exists as the dimer¹²⁰, as no carbonyl absorption could be detected in the infrared spectrum.

PREPARATION OF DIHYDROTHIOPHENES

All the dihydrothiophenes listed in Table 3 were prepared by the following procedure.

The appropriate phosphonium salt (0.01 mol) was dissolved in 50 ml of dry pyridine in a 100 ml flask fitted with magnetic stirring, a reflux condenser and a nitrogen inlet. Triethyl amine (0.015 mol) was added and the mixture was stirred at room temperature for 30 min. The appropriate mercaptocarbonyl compound (0.01 mol) was added, the system was purged with nitrogen, and the solution was heated at reflux for the time indicated in Table 3. The cooled solution was poured in 600 ml of water and extracted twice with 100 ml of ether and twice with 100 ml of pentane. The combined organic layers were washed with two 100 ml portions of 10% hydrochloric acid and dried. The solution was reduced in volume to ca. 10 ml and chromatographed on alumina using pentane as the eluent. This removed all phosphorus containing and coloured materials. The solvent was removed to yield the dihydrothiophene, which glc analysis showed to be greater than 95% pure. Analytical samples were collected by glc (Column A). Indices of refraction and nmr spectra are shown in Table 4. Except for lack of carbonyl absorption, the infrared spectra were uninformative.

KETO SULFIDE 44

When salt 23 and mercaptoketone 10 were allowed to react under the conditions given for the preparation of the dihydrothiophenes, elution of the chromatographic column with pentane afforded a 52% yield of 44 as a pale yellow oil: nmr (CCl_4) δ 7.20 (s,5), 5.28 (d,1,J=1), 5.15 (m,1), 3.32 (d,2,J=1), 2.10 (s,3), 1.37 (s,6); ir 1720 cm^{-1} .

Anal. Calcd. for $C_{14}H_{18}OS$: C, 71.77; H, 7.74; S, 13.66. Found: C, 71.93; H, 7.73; S, 13.72.

(Z)-1-(1-CYCLOHEXENYL)PROPENE¹²¹

To a suspension of 7.42 g (0.02 mol) of ethyltriphenylphosphonium bromide in 150 ml of dry tetrahydrofuran was added a solution of 2.2 g (0.02 mol) of potassium tert-butoxide in 25 ml of the same solvent dropwise with stirring and under nitrogen. The mixture was stirred at ambient temperature for 25 min, and 2.2 g (0.02 mol) of cyclohexanecarboxaldehyde was added slowly with stirring. The milky solution was stirred overnight and added to a mixture of 100 ml of water and 100 ml of ether, and the organic layer was separated and concentrated to 20 ml. After addition of 100 ml of pentane, the mixture was filtered, concentrated and distilled to give 1.4 g (55%) of a mixture of dienes bp 62-65° (12 mm). Glc analysis (Column B, 130°) showed the mixture to consist of 24% (E)- and 76% (Z)-isomer. The latter was collected: nmr (CCl_4) δ 5.81-4.95 (m, 3), 2.40-1.85 (m, 4), 1.84-1.40 (m, 7); ir (CCl_4) 700(m), 720(s), 800(m), 920(s), 970(w), in a agreement with the literature values^{121, 122}. The retention time was identical with that of the minor isomer obtained from 28 via oxidation and pyrolysis.

E-1-(1-CYCLOHEXENYL)PROPENE¹²¹

The pure (Z)-isomer was dissolved in 5 ml of petroleum ether and a crystal of iodine was added. The flask was irradiated for 16 h with a 60 watt incandescent bulb. Glc analysis showed a quantitative conversion to the (E)-isomer, identical in all respects with the major

isomer obtained from 28 via oxidation and pyrolysis.

GENERAL PROCEDURE FOR OXIDATION OF THE DIHYDROTHIOPHENES

The dihydrothiophene (0.01 mol) was dissolved in 50 ml of methylene chloride and cooled in an ice bath. m-Chloroperbenzoic acid (0.02 mol) was added in two portions (5 min) and the solution was stirred for 3 h at 0° and overnight at ambient temperature. The filtered solution was added with 50 ml saturated aqueous sodium carbonate, dried and concentrated to give a quantitative yield of sulfone, which was used directly.

SULFONE PYROLYSIS

The sulfone was injected into the injection port (280°) of the gas chromatograph fitted with column B. The dienes were eluted after sulfur dioxide and were collected, individually where possible, for spectral analysis, and were compared to authentic samples where required.

2,4-HEXADIENE, obtained from 33, was separated into the (E,Z)- and (E,E)-isomers, which were identified by comparison of spectra and retention times with those of authentic samples¹²³.

2,4-HEPTADIENE,¹²⁴ obtained from 34, was separated into the (2E,4Z)-isomer [nmr (CCl₄) δ6.41-5.05 (m,4), 2.08 (q,2,J=7.5), 1.70 (d,3,J=6), 1.0 (t,3,J=7.5); ir (CS₂) 715(s), 765(m), 780(m), 840(m), 900(w), 950(s), 985(s)] and the (E,E)-isomer [nmr (CCl₄) δ6.07-5.01 (m,4), 2.02 (q,2,J=7.5), 1.65 (d,3,J=6), 1.0 (t,3,J=7.5); ir (CS₂) 820(w), 895(m), 930(m), 950(m), 985(vs)].

2-METHYL-3,5-OCTADIENE, obtained from 35, was separated into two isomers.

The major one [nmr (CS_2) δ 6.0-5.12 (m,4), 2.45-1.76 (m,3), 0.96 (d,6,J=6.5), 0.98 (t,3,J=7.5); ir (CS_2) 700(w), 860(m), 900(w), 990(s)] was identified as the (3E, 5E)-isomer. The other isomer showed nmr (CS_2) δ 6.20-5.05 (m,4), 2.37-1.78 (m,3), 1.02 (d,6,J=7), 0.98 (t,3,J=7.5); ir (CS_2) 700(m), 861(s), 950(m), 985(m). Although the (3Z, 5E)-isomer cannot be excluded by these data, we favor 2-methyl-(3E,5Z)-octadiene for this compound. Anal. Calcd. for C_9H_{16} : m/e 124.12520. Found: m/e 124.12582.

3-METHYL-2,4-HEXADIENE,¹²⁵ was obtained from 36. The major isomer was obtained pure and by its spectra shown to be the (2E, 4E)-isomer [nmr (CCl_4) δ 6.07-5.05 (m,3), which contained the low-field half of an AB quartet centered at δ 5.95, $J_{\text{AB}}=15$, 1.86-1.55 (m,9); ir (CS_2) 772(s), 840(m), 927(vs), 970(vs), 1030(m)]. Not enough of the minor isomer could be obtained for nmr but its ir spectra 825(m), 927(w), 964(s) suggested that no cis-disubstituted double bond was present and a mixture of the two isomers enriched in the minor one showed a very complex absorption at δ 5.66-5.05, strongly reminiscent of (2E, 4Z)-hexadiene. On this basis we assign it the structure 3-methyl-(2Z,4E)-hexadiene.

3-METHYL-2,4-HEPTADIENE, was obtained from 37. The major component was separated and identified as the (2E, 4E)-isomer [nmr (CCl_4) δ 6.06-5.01 (m,3), 1.90 (q,2,J=7), 1.74-1.48 (m,6), 0.97 (t,3,J=7); ir (CS_2) 700(w), 795(m), 810(w), 860(s), 965(s)]. Not enough of the minor isomer would be obtained pure for nmr analysis but on the basis of the infrared spectrum [(CS_2) 700(m), 760(w), 865(vs), 967(s)], we believe that the majority

of the material must possess a trans-disubstituted double bond and therefore we designate it as the (2Z, 4E)-isomer. Contamination of the material with (2E, 4Z)-isomer was not noticed but cannot be excluded.

Anal. Calcd. for C_8H_{16} : m/e 110.10955. Found: m/e 110.10969.

3-ETHYL-2,4-HEXADIENE¹²⁵ was obtained from 38. It could not be separated into its isomeric components but analysis of the spectra of the mixture was done as follows. The nmr absorption for the three vinyl protons occurred between δ 6.36 and 5.00 and included the low-field half of an AB quartet ($J=15$), the intensity of which suggested that all the material contained a trans-disubstituted double bond. The absence of a strong infrared absorption below 800 cm^{-1} confirmed this. The remainder of the nmr spectrum showed δ 2.38-1.92 (q, 2, $J=7$), 1.90-1.55 (m, 6) and two overlapping triplets, $J=7.5$ centered at δ 1.01 and 0.98 whose relative intensities were 25:75. This is consistent with a mixture of 75% 3-ethyl-(2E, 4E)-hexadiene and 25% of the (2Z, 4E)-isomer, in good agreement with results of glc analysis of 38. The ir spectrum of the mixture showed 780(w), 825(w), 930(w), 965(s).

3-ETHYL-2,4-HEPTADIENE was obtained from 39. It could not be separated into its components under any condition. The mixture of isomers showed nmr (CCl_4) δ 6.45-5.05 [m, 3, which contained the low-field portion of an AB quartet centered at 5.91 ($J_{AB}=15$)], 2.48-1.88 (m, 4), 1.67 (d, 3, $J=6$), 1.01 (t, 3, $J=7$), 0.97 (t, 3, $J=7$); ir (CS_2) 760(w), 800(w), 900(w), 960(vs).
Anal. Calcd. for C_9H_{16} : C, 87.02; H, 12.98. Found: C, 86.89; H, 12.84.

3-ETHYL-6-METHYL-2,4-HEPTADIENE was obtained from 40 and was separated into the (2E, 4E)-isomer [nmr (CCl₄) δ 5.87-5.07 (m,3), 2.45-1.92 (m,3), 1.61 (d,3,J=7), 0.97 (d,6,J=6), 0.96 (t,3,J=6); ir (CS₂) 810(m), 860(w), 950(m), 975(vs)] and the (2Z, 4E)-isomer [nmr (CCl₄) δ 6.37-5.02 (m,3), 2.55-1.82 (m,3), 1.66 (d,3,J=7), 1.03 (d,6,J=6), 1.0 (t,3,J=7.5); ir (CS₂) 800(m), 945(m), 968(s)]. This latter assignment of structure was based on the absence of any significant absorption below 800 cm⁻¹, which suggested the absence of a cis-disubstituted double bond.

Anal. Calcd. for C₁₀H₁₈: C, 86.88; H, 13.12. Found: C, 86.70; H, 13.24.

1-(1-CYCLOHEXENYL)PROPENE¹²¹ was obtained from 28. The major and minor isomers were identical with the authentic samples of the (E)- and (Z)-isomers, respectively.¹¹

1-(1-CYCLOHEXENYL)BUTENE¹²¹ was obtained from 29. The vinyl region of the nmr spectrum was very similar to that of the (E)-isomer obtained from 28 and on that basis was assigned the same configuration: nmr (CCl₄) δ 6.11-5.20 (m,3, which contained the low-field half of an AB quartet, J=15), 2.34-1.33 (m,10), 1.00 (t,3,J=6.5).

1,4-BIS-(DIMETHYLSULFONIO)-2-BUTENE DIBROMIDE¹²⁷ 77

Dimethyl sulfide (7.5 g, 0.12 mol) was added to 1,4-dibromo-2-butene (10.7 g, 0.05 mol) and the resulting solution was heated to 80° in a sealed tube for 13 h. Filtration of the resulting hygroscopic solid led to 10 g (60%) of the desired sulfonium salt mp 141-143° (lit.¹²⁷ mp 136-137°; nmr (D₂O) δ 6.25 (m,2), 4.92 (m,4), 2.92 (s,12).

1,4-BIS-(TETRAMETHYLENESULFONIO)-2-BUTENE DIBROMIDE 66

1,4-Dibromo-2-butene (10.7g, 0.05 mol) and 17.6 g of tetrahydrothiophene was added to 20 ml of benzene. The resulting solution was stirred at room temperature under a blanket of nitrogen for 1 week at which time the mixture was filtered in an inert atmosphere and the solid recrystallized (methanol/pentane). The yield of the salt was 13 g (66%) mp 119-121⁰; nmr (D₂O) δ6.4-6.1 (m,2), 4.2-3.95 (m,4), 3.97-3.2 (m,8), 2.65-2.1 (m,8). Anal. Calcd. for C₁₂H₂₂S₂Br₂: C, 36.93; H, 5.68. Found: C, 36.82; H, 5.79.

MICHAEL-WITTIG REACTION OF 63 USING N-BUTYL LITHIUM AS BASE

To 1.8 g (0.005 mol) of 77 in 30 ml of tetrahydrofuran was added 1 equivalent of n-butyl lithium in hexane in a nitrogen atmosphere. After stirring a short time, the orange solution became colourless and precipitated a white solid. At this time 0.53 g (0.005 mol) of benzaldehyde and 0.61 g (0.005 mol) of sodium thiophenoxide were added. The mixture was stirred overnight. The mixture was added to 600 ml of water and extracted with two 100 ml portions of pentane. The organic layer was washed twice with 100 ml of water and dried. Removal of the solvent led to a solid (1.5 g) which proved to be 1,4-bis-(phenylthio)-2-butene (100%). mp 78-80⁰ (lit.¹²⁸ mp 80⁰), nmr (CDCl₃) δ7.29 (s,10), 6.6 (m,2), 3.5 (m,4).

1-(DIMETHYLSULFONIO)-1,3-BUTADIENE BROMIDE 63

Into a flask flushed with nitrogen was added 1.8 g (0.005 mol) 77 in a 25 ml of dry tetrahydrofuran. Slowly 1 equivalent of n-butyl lithium (2.2 M in hexane) was added and the resulting orange solution was stirred for several hours until the solution was colourless. The

solid precipitate was filtered in a nitrogen dry box and washed with pentane:ether to yield 0.8 g (85%) of the desired salt. mp 83-88⁰ (lit.¹²⁷ mp 89⁰); nmr (D₂O) δ 7.55-5.6 (m,5), 3.05 (s,6).

REACTION OF 66 WITH N-BUTYL LITHIUM

Into a dry flask containing 50 ml of anhydrous ether was added 1.95 g (0.005 mol) of 66. After the flask was purged with nitrogen, 2.3 ml of n-butyl lithium (2.25 M in hexane) was added dropwise. A yellowish-green colour developed which dissipated after stirring for 15 min at room temperature. Filtering the resulting clear solution afforded 1.85 g of a white solid whose nmr was consistent with that of 66.

CIS,TRANS-1-BUTENYL METHYL SULFIDE

n-Butyl lithium (21 ml, 2.4 M in hexane) was added dropwise to a mixture of methylthiomethyltriphenylphosphonium chloride¹²⁹ (17.9 g, 0.05 mol) in 200 ml of dry THF in a 500 ml r.b. flask which had been flushed with nitrogen. After the addition was complete, the resulting tangerine orange solution was stirred for 15 min after which time propionaldehyde (3.5 g, 0.06 mol) was slowly introduced into the flask. The colourless mixture was refluxed for 10 h. The cooled solution was filtered, added to 600 ml of water and extracted twice with 150 ml of pentane. The dried organic layer was concentrated in vacuo to approximately 35 ml, cooled, filtered and distilled to yield 2.6 g (51%) of the title compound. bp 123-126⁰ (lit.¹³⁰ bp 123-126⁰) nmr (CCl₄) δ 6.08-5.16 (m,2), 2.5-1.7 (m,2), 2.2 (s,3), 1.4-0.85 (2t,3).

1-BUTENYLDIMETHYLSULFONIUM TETRAFLUOROBORATE

The following procedure is representative of our synthesis of vinylsulfonium salts: Into a 100 ml r.b. flask which was purged with nitrogen was added 4.5 g (0.042 mol) of 1-butenyl methyl sulfide in 1 ml of methylene chloride and 6.7 g (0.045 mol) of trimethyloxonium tetrafluoroborate¹³¹. The flask was kept in a freezer (-25°C) for 7 h after which time 40 ml of acetonitrile was added. To the rusty coloured solution was added 100 ml of anhydrous ether and an oil separated from the reaction mixture. Upon removing the solvent in vacuo and triturating the resulting oil with anhydrous ether a light rusty coloured semi-solid was obtained (8.5 g, 100%). The semi-solid was very hygroscopic and thus usually used in situ. nmr (CD₃CN) δ 7.25-6.10 (m, 2); 2.90 (s, 6), 2.45 (2q, separated by 1 Hz, 2, J=8), 1.15 (t, 3, J=8).

PREPARATION OF TETRAHYDROTHIOPHENE EPOXIDES

The tetrahydrothiophene epoxides listed in Tables 8 and 9 were prepared in the following manner.

The vinylsulfonium salt (0.01 mol) was prepared in a 100 ml r.b. flask (vide supra). The solvent was removed in vacuo and replaced by 25 ml of acetonitrile. Anhydrous ether (15 ml) was added and the mixture was cooled to -45°. The flask was purged with nitrogen and a solution of the appropriate α -mercaptocarbonyl compound (1 molar equivalent) was added all at once. The resulting golden solution was stirred for 3 h and then allowed to warm up to ambient temperature. The solution was poured into 600 ml of water and extracted with pentane (2 x 150 ml) and with 150 ml of ether. The combined organic layers were washed twice with 500 ml H₂O, once with 250 ml of 1 N sodium hydroxide and finally with saturated

aqueous sodium chloride solution. After removing the solvent from the dried organic layer, glc analysis was performed and spectral data was obtained from the products collected by glc (Column A) or by TLC (silica gel, 5% ether in petroleum ether).

ALLYLTETRAMETHYLENESULFONIUM BROMIDE 61

Into 50 ml of anhydrous diethyl ether was added 17.6 g (0.02 mol) of tetrahydrothiophene and 24.2 g (0.02 mol) of allyl bromide. Refluxing the solution for 5 days and filtering the cooled solution afforded 21 g (50%) of the desired salt (hygroscopic!). mp 65-67° (lit.¹³² mp 68-69°) nmr (CD₃CN) δ6.40-5.45 (m,3), 4.4 (d,2,J=6), 3.85-3.35 (m,4), 2.55-2.2 (m,4),

REACTION OF ALLYLTETRAMETHYLENESULFONIUM BROMIDE WITH 11

Allyltetramethylenesulfonium bromide 61 (1.0 g, 0.005 mol) was added to 30 ml dry pyridine containing 0.5 g of triethyl amine in a 100 ml flask under a blanket of nitrogen. The mixture was refluxed for 2 h after which time 0.65 g (0.005 mol) of α-mercaptocyclohexanone was added. After refluxing overnight (10 h) the solution was cooled and added to 600 ml of water, extracted with pentane (2 x 150 ml), ether (150 ml) and the combined organic layers were rewashed with water (2 x 500ml), 1 N sodium hydroxide, and finally with saturated brine solution. Glc analysis of the dried and concentrated organic layer led to the recovery of 2-allylthiocyclohexanone and tetrahydrothiophene as the two major products. For 2-allylthiocyclohexanone 62: nmr (CDCl₃) δ6.15-4.90 (m,3), 3.5-1.4 (m,9), 3.1 (d,2,J=6.5); ir (CDCl₃) 1712 cm⁻¹: Found for C₉H₁₄OS: m/e 170.

REACTION OF ALLYLDIPHENYLSULFONIUM TETRAFLUOROBORATE WITH
PYRIDINE: TRIETHYL AMINE

Allyldiphenylsulfonium tetrafluoroborate prepared in the manner described by Trost⁸⁶ was added to pyridine containing a molar equivalent of triethyl amine and the mixture was refluxed for 8 h after which time the solution was dark brown. Precipitation of an oil from the reaction pot with anhydrous ether led to the recovery of the starting allyl salt (65%) and no detectable amount of the vinyl isomer. nmr (CDCl₃) δ 8.0-7.3 (m, 10), 5.65-5.2 (m, 3), 4.75 (d, 2, J=6)..

GENERAL PROCEDURE FOR THE SYNTHESIS OF β -BROMOSULFONIUM SALTS

The sulfonium salts listed in Tables 11 and 12, were prepared in this manner.

Into 105 ml of dimethyl sulfide contained in a 500 ml r.b. flask (nitrogen atmosphere) was added 20 g (0.125 mol) of bromine dropwise with stirring. (caution!) The temperature of the reaction was controlled with an ice bath and was not allowed to rise above room temperature. After the addition was complete (1 hour), stirring was continued for 0.5 h. To the resulting yellow precipitate was added 0.13 mol of the appropriate olefin all at once and the mixture was stirred for 24 h at ambient temperature. Addition of 100 ml of anhydrous ether and filtering the white solid in a dry box led to the β -halosulfonium salt which was dried and stored at room temperature in a vacuum dessicator.

REACTION OF N-BROMOSUCCINIMIDE AS ROUTE TO β -BROMOSULFONIUM SALTS

Into a dry flask purged with nitrogen was added 100 ml of dimethyl sulfide and 4.5 g (0.06 mol) of cyclohexene. N-bromosuccinimide (9 g, 0.05 mol) was added in small portions and a yellow precipitate formed. The mixture was stirred overnight after which time a white, hygroscopic solid was isolated by filtration to yield 9.5 g of a compound whose nmr spectrum was consistent with the structure 70 ($X = Br$). mp $71-77^{\circ}C$. nmr (CF_3COOH , TSP) δ 2.75 (s,4), s.6 (s,6).

DEHYDROBROMINATION OF 72 USING SILVER OXIDE

Silver oxide (2.5 g) was added to 3.0 g (0.01 mol) of 76 in 50 ml of acetonitrile. The flask was purged with nitrogen, covered with aluminium foil, and stirred at ambient temperature for 16 h. The mixture was filtered carefully and the solvent was removed. The addition of ether to the resulting oil produced the semi-solid 1-dimethylsulfonio-cyclohexene (0.65 g, 30%). nmr (CD_3CN) δ 7.0 (m,1), 3.2 (s,6), 2.6-1.4 (m,8).

REACTION OF 1-BROMO-2-DIMETHYLSULFONIOCYCLOPENTANE BROMIDE 73 WITH α -MERCAPTOKETONE 10

The β -bromo salt 73 (2.9 g, 0.01 mol) was added to a flask containing 50 ml of absolute methanol. The mixture was purged with nitrogen and cooled to $-78^{\circ}C$ (dry ice-acetone). At this time 1.2 g of the mercaptan 10 in 5 ml dry pyridine was added dropwise (5 min). The resulting solution was stirred at $-78^{\circ}C$ for 4 h and then allowed to reach ambient temperature. Potassium tert-butoxide (1.12 g, 0.01 mol) was added in small portions

(15 min) while the reaction mixture was cooled with an ice bath and then the mixture was stirred at room temperature for 8 hours. The solution was poured into 700 ml of water and extracted twice with 150 ml ether. The combined organic layers were washed with 5 x 600 ml water, dried and the solvent removed to yield 0.9 g of a yellow oil. Glc analysis of this oil (Column A, 220°) indicated that the major organic compound present was 3-methyl-3-methylthio-2-butanone. nmr (CDCl₃) δ 2.3 (s,3), 1.85 (s,3), 1.35 (s,6).

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